10720839 IN SITU SUBSTRATE TEMPERATURE MONITORING

Type	L#	Hits	Search Text	DBs	Time Stamp	Comments
BRS	L1	1	10/608,091	US-PGPUB; USPAT	5/16/05 14:27	in IDS.
BRS	L2	60	(US-20010014111-$ or US-20020048311-$ or US-20030070758-$ or US-20030080112-$ or US-20040261721-$).did. or (US-4262035-$ or US-4854727-$ or US-4880314-$ or US-4890245-$ or US-4913790-$ or US-4919542-$ or US-4969748-$ or US-4984902-$ or US-5021980-$ or US-5156461-$ or US-5180226-$ or US-5225245-$ or US-5255286-$ or US-5388909-$ or US-5508934-$ or US-5549756-$ or US-5568978-$ or US-5597609-$ or US-5690429-$ or US-5703342-$ or US-5743644-$ or US-5755511-$ or US-5806980-$ or US-5820261-$ or US-5823681-$ or US-5875416-$).did. or (US-5902504-$ or US-6004029-$ or US-6056433-$ or US-6062729-$ or US-6072163-$ or US-6080969-$ or US-6086245-$ or US-6106148-$ or US-6116779-$ or US-6132081-$ or US-6159607-$ or US-6164816-$ or US-6179466-$ or US-6190037-$ or US-6191399-$ or US-6200023-$ or US-6283630-$ or US-6299346-$ or US-6416890-$ or US-6481886-$ or US-6507007-$ or US-6561694-$ or US-6575622-$ or US-6596973-$ or US-6616331-$ or US-6666577-$ or US-6703592-$).did. or (US-6798036-$ or US-6799888-$).did.	US-PGPUB; USPAT	5/16/05 14:47	tagged so far.
BRS	L4	25	("6514376"|"6605955"|"6635117"|"4919542"|"5200023"|"5388909"|"5467732"|"5660472"|"5683180"|"5746513"|"5755511"|"5769540"|"5848842"|"5967661"|"5996415"|"6062729"|"6082892"|"6112595"|"6174080"|"6179466"|"6182510"|"6481886"|"5568978"|"5490728"|"5775808").PN.	US-PGPUB; USPAT	5/16/05 14:42	cited in IDS in THIS application by Applicant.
BRS	L6	2	4 and 3	US-PGPUB; USPAT	5/16/05 14:43	already cited.
BRS	L7	5	4 and 2 not 3	US-PGPUB; USPAT	5/16/05 14:43	browse.
BRS	L3	12	("6191399"|"5225245"|"6062729"|"6116779"|"6106148"|"4854727"|"6575622"|"5823681"|"6283630"|"20010014111"|"5021980"|"4919542").PN.	US-PGPUB; USPAT	5/16/05 14:47	cited in 892 previously.
BRS	L8	25	5583737	US-PGPUB; USPAT	5/16/05 14:48	browsed - cited in one of above patents.
BRS	L9	18	4 not 3 not 2 not 8	US-PGPUB; USPAT	5/16/05 15:54	browsed - removed duplicates.
BRS	L10	20	5 not 4 not 3 not 2 not 8	US-PGPUB; USPAT	5/16/05 15:54	no duplicates - browsed these - see next.. mostly chucks.
BRS	L5	20	("5192849"|"5310453"|"5382311"|"5609720"|"5671116"|"5675471"|"5835334"|"6077357"|"6083344"|"6108189"|"6179921"|"6182602"|"6189483"|"6231776"|"6310755"|"6373681"|"6377437"|"6378600"|"6394797"|"6451157").PN.	US-PGPUB; USPAT	5/16/05 15:55	cited in IDS in related application 10/608,091 cited in IDS.

Type	L#	Hits	Search Text	DBs	Time Stamp	Comments
IS&R	L11	468	((374/1) or (374/2)).CCLS.	US-PGPUB; USPAT	5/16/05 16:05	
IS&R	L12	1480	((374/120) or (374/126) or (374/127) or (374/147) or (374/141)).CCLS.	US-PGPUB; USPAT	5/16/05 16:05	
IS&R	L13	1933	((427/8) or (427/585)).CCLS.	US-PGPUB; USPAT	5/16/05 16:06	
IS&R	L14	842	(438/16).CCLS.	US-PGPUB; USPAT	5/16/05 16:06	
IS&R	L15	408	((356/43) or (356/45)).CCLS.	US-PGPUB; USPAT	5/16/05 16:07	
BRS	L17	29	(12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/16/05 16:09	
BRS	L18	73	(13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/16/05 16:09	
BRS	L19	50	(14 not 13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/16/05 16:10	
BRS	L16	19	11 and @pd>"20041209"	US-PGPUB; USPAT	5/16/05 16:11	update
BRS	L20	2	(15 not 14 not 13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/16/05 16:18	update
BRS	L22	0	17 and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/16/05 16:19	
BRS	L23	2	17 and plasma	US-PGPUB; USPAT	5/16/05 16:19	update
BRS	L21	25	(18 or 19) and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/16/05 16:19	update
IS&R	L24	528	(427/535).CCLS.	US-PGPUB; USPAT	5/16/05 16:44	
IS&R	L25	269	(438/9).CCLS.	US-PGPUB; USPAT	5/16/05 16:45	
BRS	L26	796	24 or 25	US-PGPUB; USPAT	5/16/05 16:45	
BRS	L27	1	24 and 25	US-PGPUB; USPAT	5/16/05 16:45	BROWSED
BRS	L28	529	26 and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/16/05 16:46	
BRS	L29	24	28 and (chuck or susceptor or pedestal) AND CALIBRAT$4	US-PGPUB; USPAT	5/16/05 16:47	BROWSED
IS&R	L30	610	(374/179).CCLS.	US-PGPUB; USPAT	5/16/05 17:11	
IS&R	L31	509	(374/121).CCLS.	US-PGPUB; USPAT	5/16/05 17:11	
BRS	L32	30	(30 or 31) and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/16/05 17:12	

KEY WORDS:

IPC(7) Classification:	XREF?	CLASS 374:	
update	or	374/1	
update		374/2	
update		374/120	
update		374/126	
update		374/127	
update		374/147	
update	XR	374/141	
today MAY 16	XR	374/179	
today MAY 17	XR	374/121	
		CLASS 392/	
		392/416	
		CLASS 118/	
		118/724	
		118/725	
		CLASS 356	
update		356/43	
update	XR	356/45	
		392/418	
		438/9	... Plasma etching
		438/14	WITH MEASURING OR TESTING
		438/16	. Optical characteristic sensed
		438/485	.. Deposition utilizing plasma (e.g., glow discharge, etc.)
		438/798	. Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)
		438/907	CONTINUOUS PROCESSING
		438/909	CONTROLLED ATMOSPHERE
		356/43	OPTICAL PYROMETERS
		356/45	. Plural color
update	XR	427/8	MEASURING, TESTING, OR INDICATING
		427/165	.. Glass
		427/166	... Vapor depositing
		427/573	... With heated substrate
update		427/585	. Chemical vapor deposition (e.g., electron beam or heating using IR, inductance, resistance, etc.)
today MAY 16		427/535	... Plasma (e.g., cold plasma, corona, glow discharge, etc.)
		CLASS 438	
		438/5	INCLUDING CONTROL RESPONSIVE TO SENSED CONDITION
		438/6	. Interconnecting plural devices on semiconductor substrate
		438/7	. Optical characteristic sensed
		438/8	.. Chemical etching
today MAY 16	XR	438/9	... Plasma etching
		438/14	WITH MEASURING OR TESTING
		438/15	. Packaging (e.g., with mounting, encapsulating, etc.) or treatment of packaged semiconductor
update	XR	438/16	. Optical characteristic sensed
later 1		438/798	. Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)
later 2,		438/485	.. Deposition utilizing plasma (e.g., glow discharge, etc.)
		CLASS 219/	
.		219/497	ask ? later
.		219/505	ask ? later
.		219/390	ask ? later

only here
ACI Dempsey
Joe Pelham
see MARK PASCHAL

SRNT 5/16/05

Pruchnic, Stanley

Subject: Class 438 SEMICONDUCTOR DEVICE MANUFACTURING: PROCESS

Status: Not Started
Percent Complete: 0%

Total Work: 0 hours
Actual Work: 0 hours

Owner: Pruchnic, Stanley

438/5 INCLUDING CONTROL RESPONSIVE TO SENSED CONDITION
438/6 . Interconnecting plural devices on semiconductor substrate
438/7 . Optical characteristic sensed
438/8 .. Chemical etching
438/9 .. Plasma etching

438/14 WITH MEASURING OR TESTING
438/15 . Packaging (e.g., with mounting, encapsulating, etc.) or treatment of packaged semiconductor
438/16 . Optical characteristic sensed

==========================
438/485 .. Deposition utilizing plasma (e.g., glow discharge, etc.)

438/758 COATING OF SUBSTRATE CONTAINING SEMICONDUCTOR REGION OR OF SEMICONDUCTOR SUBSTRATE

438/795 RADIATION OR ENERGY TREATMENT MODIFYING PROPERTIES OF SEMICONDUCTOR REGION OF SUBSTRATE (E.G., THERMAL, CORPUSCULAR, ELECTROMAGNETIC, ETC.)
438/796 . Compound semiconductor
438/797 .. Ordering or disordering
438/798 . Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)

Pruchnic, Stanley

Subject: Class 427 COATING PROCESSES

Status: Not Started
Percent Complete: 0%

Total Work: 0 hours
Actual Work: 0 hours

Owner: Pruchnic, Stanley

Class 427 COATING PROCESSES

427/8 MEASURING, TESTING, OR INDICATING

427/569 . Plasma (e.g., corona, glow discharge, cold plasma, etc.)
427/570 .. Utilizing plasma with other nonionizing energy sources
427/571 ... With magnetic enhancement
427/572 ... Light as energy source
427/573 ... With heated substrate

427/585
. Chemical vapor deposition (e.g., electron beam or heating using IR, inductance, resistance, etc.)

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427/162 OPTICAL ELEMENT PRODUCED

427/163.1 . Polarizer, windshield, optical fiber, projection screen, or retroreflector
427/163.2 .. Optical fiber, rod, filament, or waveguide
427/163.3 .. Projection screen
427/163.4 .. Retroreflector (e.g., light reflecting small spherical beads, etc.)
427/164 . Transparent base
427/165 .. Glass
427/166 ... Vapor depositing

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DRAFT NOTES

US 6191399 B1 (Van Bilsen; Frank B. M.)

VAN BILSEN, as described in the previous Office Action, discloses, in a CVD reactor 10, a wafer support structure 18, including a wafer holder 20, and wafer 16. A non-contact temperature sensor 21 such as a pyrometer is in the chamber, as well as a thermocouple 28. The support structure includes a spider 22, however, VAN BILSEN does not disclose a chuck as claimed by Applicant. Thermocouple readings are used to periodically calibrate the pyrometer (Fig. 4; Col. 7). VAN BILSEN's assumption (Col. 7, Lines 25-32) that thermocouple 28 is more reliable than the pyrometer is not generally valid for the case of a working plasma chamber, that is, in use while processing a substrate. VAN BILSEN's method and device would not function as claimed by Applicant in the presence of a plasma. Therefore, one having ordinary skill in the art would not have found it obvious to use the method and device as claimed by Applicant in a plasma processing system.

Importantly, VAN BILSEN requires the temperature measurement using the thermocouple to be done at the same time as the temperature measurement using the pyrometer, *during a steady state portion of the recipe* (Col. 7, Lines 17-24).

VAN BILSEN teaches away from the claimed invention which requires, in a plasma processing system, the method measuring a first chuck temperature using a physical measuring device in thermal contact with said chuck and in the absence of a plasma in said plasma processing system; and also determining a temperature of said substrate during plasma processing, wherein said plasma is present in said plasma processing system as claimed by Applicant in Claim 1 and in Claim 25.

THEVENARD (IDS cite No. 33) discloses a method for calibrating a spectroscopic (infrared) wafer temperature measurement and states the application of intended use on Page 44: "We are ultimately thinking of a device that could be integrated in the plasma chamber of an etching tool (for instance) and that would measure temperature in real time." THEVENARD recognizes the need, but does not provide the solution of the problem.

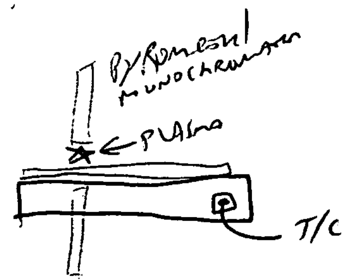
HIRSCHER (IDS cite No. 27) "This backside gas injected at a defined gas pressure and at a certain gap of the wafer to the pedestal - improves the heat transfer dramatically."

DRS vs. Other Techniques (IDS cite No. 29) Of thermocouples, "Disadvantages: In order to work, the thermocouples must make mechanical contact with the sample. In cases where the sample is rotating or the sample is immersed in a hostile environment (such as harsh chemicals, plasma discharge, etc.) then thermocouples cannot be used. As well, in many cases, it is not acceptable to touch the surface of the device during processing. In addition, care must be taken to insure that the thermocouples do not conduct significant heat away from the sample."

Examples of some illustrative chambers are described in U.S. Pat. No. 5,583,737, issued Dec. 10, 1996; U.S. Pat. No.

CKM 4/15/05

SRNT



AMENDMENTS TO THE CLAIMS:

Claim 1 (currently amended): In a plasma processing system, a method of determining the temperature of a substrate, comprising:

positioning said substrate on a substrate support structure, wherein said substrate support structure includes a chuck;

creating a temperature calibration curve for said substrate, said temperature calibration curve being created by measuring at least a first substrate temperature with an electromagnetic measuring device, and measuring a first chuck temperature with a physical measuring device in thermal contact with said chuck during a first isothermal state of said substrate, in the absence of a plasma in said plasma processing system;

employing a measurement from said electromagnetic measurement device and said temperature calibration curve to determine a temperature of said substrate during plasma processing, wherein said plasma is present in said plasma processing system.

Claim 2 (original): The method of claim 1, further including the step of measuring a second substrate temperature with said electromagnetic measuring device, and measuring a second chuck temperature with said physical measuring device during a second isothermal state.

Claim 3 (original): The method of claim 1, wherein said substrate is positioned between said plasma and said electromagnetic measuring device.

Claim 4 (original): The method of claim 1, wherein said substrate support structure further comprises said physical temperature measuring device.

OR=374/1

Claim 5 (original): The method of claim 1, where said electromagnetic measuring device comprises a narrow-band pyrometer.

XR 374/121
XR 374/179
XR 374/141

Claim 6 (original): The method of claim 1, where said electromagnetic measuring device comprises a monochrometer.

XR 356/45
XR 427/8
XR 438/9, 16

118/

Oeppelham

219/390 [general wafer proc. system - w/ wider T control (xxx)]
392/ NOT REQUIRED

is the "second radiation constant", and L1,L2 are "effective wavelengths" corresponding to λ_1,λ_2 respectively. The effective wavelength of a thermometer is the wavelength of an equivalent (ideal) monochromatic thermometer - i.e. one which matches the calibration function of the actual thermometer over the temperature range of interest.

Brightness temperatures are the temperatures one derives directly from the thermometer signals S1,S2 (using Planck's Law) without any correction for emissivity effects.

Equations 1',2' are just equations 1,2 written in a different way - i.e. where T1,T2 are taken to be the measurands rather than S1,S2. Taken with equation 3, equations 1',2' form a three-equation, three-unknown system which can be solved for true temperature T.

This representation is useful in practice where the thermometer directly outputs brightness temperatures rather than "radiance" signals S1,S2.

If we take equations 1',2' together with equation 5 we get, with some manipulation:

$$1/T = (A+1) \,.\, 1/T1 - A \,.\, 1/T2 + B \qquad (6)$$

where $A = b.L1 / (L2 - b.L1)$
and $B = A.L2.\ln a / c2.b$
and we can solve for T from measured T1,T2 if we know A and B.

We can get the A and B needed in equation 6 in a number of ways, for example we could make a theoretical analysis of the relationship between E1 and E2, hence derive a,b and hence A,B, or we could, similarly, make an empirical study of how E1 relates to E2, hence derive a,b and hence A,B.

However, a very direct and effective way is to simply record T1,T2 in the measurement application over a period of time while also taking "reference" values of true temperature T using, for example, a contact thermometer.

A plot of 1/T-1/T1 versus 1/T1-1/T2 is formed called a "1/T" plot and then a best straight line fit to the data is made, whence the slope and intercept of the line give directly A and B respectively.

An important point to recognise is that a straight line relation in the 1/T plot is not essential to the method. A straight line follows from equation 6, which follows from equation 5 - i.e. the log-linear assumption. However, provided the empirical data forms a single-valued relation in the 1/T plot then the plot can be used directly to relate T to measured T1,T2 without any a prior assumption about the form of the E1 = f(E2) relation.

Thus, we have a purely empirical method: T1,T2,T data is collected (e.g. during system commissioning) and points entered into a 1/T plot. Any promising function is then used to fit the data and hence permit calculation of T from future measured T1,T2.

This approach which is also described in GB-A-2160971 works successfully and it is found that once an empirical 1/T relation is established it is stable and may be used over many months without adjustment.

For a metal stream, the situation can be more complex. We have found that a 1/T relation can be established which correctly accounts for the (E1 = f(E2)) behaviour of one interference (e.g. cavitation) but that other interferences occur, in a fluctuating manner, which are not correctly described by this 1/T relation.

If one interference is dominant then the result is a predominance of readings that fall on a line (not necessarily straight) in the 1/T plot but with a scatter of readings on either side of this line.

One can exploit the fast response of the thermometer to take readings in large ensembles (e.g. a thousand T1,T2 values in a one second interval). This allows one to use internal consistency to select those readings which are subject to only the single (modelled) interference and reject those that are subject to multiple interferences.

This can work as follows:

From theoretical and/or empirical studies, it is decided that interference "X" is dominant. We further establish a 1/T relation which models interference "X".

Conveniently (but not necessarily) let us assume that this 1/T relation turns out to be a straight line - i.e. our modelling gives us A and B values as per equation (6).

Initially, the computer determines from the sensed intensity pairs S1,S2, equivalent radiance pairs T_1,T_2 using a conventional "linearisation" routine. In this example, illustrated in the flow diagram form in Figure 4, the computer 12 then computes from each of the 1000 T_1,T_2 pairsa temperature T using equation 6 (step 30). The values of T are then grouped into respective temperature ranges, for example 5 celsius intervals, by incrementing respective counts depending upon each value of T which is obtained in step 30. (Step 31.)

This results in a set of counts, an example of which is indicated graphically in Figure 5. In this Figure, seven temperature ranges are defined centred on respective temperatures (defined along the horizontal axis) while the number of values falling within each temperature range is plotted on the vertical axis. In a step 32, the computer 12 determines the temperature range with the most T values, in this case temperature range 3, and outputs (step 33) to a display or printer (not shown) the mean temperature value of that temperature range. Alternatively, the value may be converted back to analogue form and used for control purposes or the like. In other methods, as described above, account

SAre

US005549756A

United States Patent [19]

Sorensen et al.

[11] **Patent Number: 5,549,756**

[45] **Date of Patent: Aug. 27, 1996**

[54] **OPTICAL PYROMETER FOR A THIN FILM DEPOSITION SYSTEM**

[75] Inventors: **Carl A. Sorensen**, Morgan Hill; **Wendell T. Blonigan**, Fremont, both of Calif.

[73] Assignee: **Applied Materials, Inc.**, Santa Clara, Calif.

[21] Appl. No.: **190,421**

[22] Filed: **Feb. 2, 1994**

[51] **Int. Cl.**^{6} **C23C 16/00**

[52] **U.S. Cl.** .... **118/715**; 118/725; 118/728; 118/723 E; 118/663; 118/666; 118/712; 118/713; 250/338.1; 374/120; 374/121; 374/127

[58] **Field of Search** .... 118/663, 666, 118/712, 713, 725, 728, 723 R, 723 IR, 723 E, 715; 250/341.6, 338.1; 374/120, 121, 127

[56] **References Cited**

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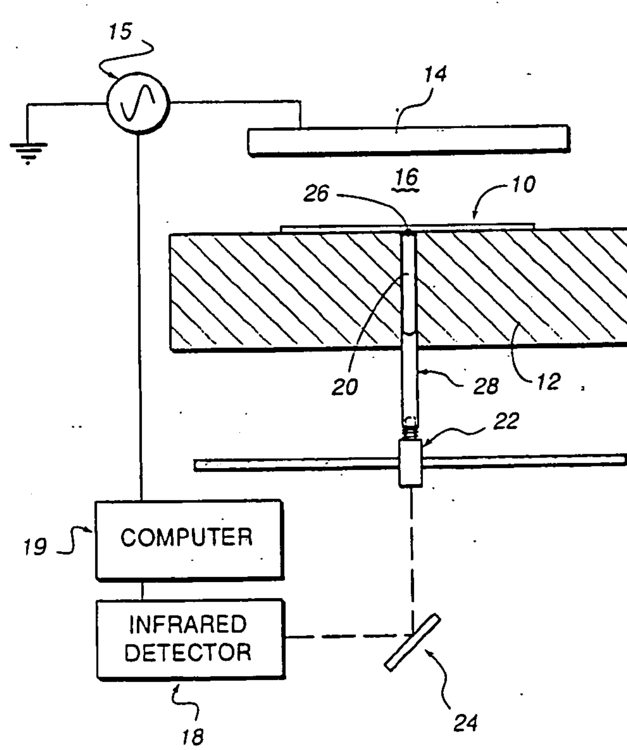
Primary Examiner—R. Bruce Breneman
Assistant Examiner—Jeffrie R. Lund
Attorney, Agent, or Firm—Loeb & Loeb LLP

[57] **ABSTRACT**

A temperature measurement system for use in a thin film deposition system is based on optical pyrometry on the backside of the deposition substrate. The backside of the deposition substrate is viewed through a channel formed in the susceptor of the deposition system. Radiation from the backside of the deposition substrate passes through an infrared window and to an infrared detector. The signal output by the infrared detector is coupled to electronics for calculating the temperature of the deposition substrate in accordance with blackbody radiation equations. A tube-like lightguide shields the infrared detector from background radiation produced by the heated susceptor.

32 Claims, 2 Drawing Sheets



Sorensen

the susceptor **12** from the backside of the deposition substrate **10**. The lightguide **28** is preferably sufficiently smooth on its inner surface so that relatively little of the radiation emitted by the deposition substrate **10** is absorbed or reflected back toward the deposition substrate.

The lightguide **28** may be a ceramic tube and, in particular, may be an alumina tube. Alumina is a suitable material for use because it is stable over a wide range of temperatures and environmental conditions and because its elemental constituents, aluminum and oxygen, are found elsewhere in the processing environment. For example, the susceptor **12** is typically formed from aluminum, and glass deposition substrates typically include oxygen as an elemental constituent. It is generally advisable to not introduce different types of material into the thin film deposition environment to avoid the dangers of contamination or undesired reaction. Potential contamination problems may arise unexpectedly due to the harsh chemical environment of the deposition chamber and because of the very energetic reactions facilitated by the plasma. It is therefore simplest to only use materials that are already present in the deposition chamber environment so that no new contamination problems arise.

Because it is used in the chemically reactive environment of the deposition chamber, the emissivity of the lightguide may vary over time. Process gases from the plasma region may reach the inner surface of the lightguide and react with the lightguide material, even if the process gases are present only in greatly reduced quantities. Thus, a variety of chemical reactions may occur over time, altering the chemical composition of the lightguide and consequently altering the optical properties of the lightguide. For the purposes of the pyrometric system described herein, one of the most important of the optical properties that might change over time is the emissivity of the lightguide. For example, if the lightguide were formed from aluminum, prolonged exposure to some of the process gases used in thin film deposition might cause the inner surface of the lightguide to be converted into aluminum oxide. Aluminum oxide typically has a higher emissivity than does a polished piece of aluminum. Additionally, the chemical reaction which converts aluminum to aluminum oxide might cause the inner surface of the lightguide to become rougher, increasing the scattering of light from the walls of the lightguide. Similar chemical reactions or physical roughening may occur with other lightguide materials, as well.

If the optical properties of the lightguide, or any other optical component along the optical path from the backside of the deposition substrate to the infrared detector, vary over time, it may be preferable to periodically recalibrate the temperature measurement system. Calibration may be accomplished in a number of different ways. A deposition substrate may be fitted with a thermocouple or other thermometer to measure the actual temperature of the substrate for comparison with the pyrometric determined temperature. A different sort of recalibration may be performed to allow the pyrometric temperature measurements to be made as a differential measurement. For example, the background temperature measurement might be made by measuring the intensity of the background radiation when a "cold" glass substrate is moved into place on the susceptor. For the purposes of calibrating the temperature measurement system, a "cold" glass substrate is one having a sufficiently low temperature that the blackbody radiation from the substrate is a negligible proportion of the total intensity collected by the infrared detector. In practice, a room temperature substrate may be sufficiently cold to perform background measurements. In such a background measurement, the primary purpose of the cold glass substrate is to shield the infrared detector from any blackbody source disposed above the usual substrate position. Either the level of background radiation or the apparent background temperature can be used as a background radiation reference signal. The background reference signal is then stored in a memory either within the calculation electronics or in the deposition system's computer **19**. Subsequent pyrometric measurements are made relative to the previously determined background radiation reference signal. In other words, the background radiation is "subtracted off" from the pyrometric measurements. The background measurement can be made as often as is necessary to maintain the accuracy of the temperature measurement.

Both aluminum and alumina may be suitable lightguide materials, but there are tradeoffs associated with the choice of one material or the other. For example, an aluminum tube having a highly polished inner surface is highly reflective and consequently is expected to have a substantially lower emissivity than an alumina tube. The use of an aluminum tube would therefore decrease the amount of background signal produced by the blackbody radiation from the walls of the lightguide. However, an alumina lightguide has greater chemical stability, and it is less likely that the optical properties of the lightguide will vary over time. Accordingly, the choice of lightguide material will often depend on the exact nature of the chemicals used for the thin film deposition. As discussed above, it is preferable that the lightguide be formed of a material already present in the deposition environment. It is, of course, possible to use a different material for the lightguide, if the material is chosen so as to not produce unacceptable contamination of the thin films deposited in the system.

A second design consideration in choosing the lightguide material is that the walls of the lightguide will conduct heat away from the deposition substrate. Such heat conduction can cause a local cold spot to develop on the surface of the deposition substrate. The surface of such a cold spot might have a temperature slightly lower than surrounding regions of the deposition substrate, and might produce measurably different electrical properties in the films deposited in that region. Unacceptable uniformity variations in the deposited thin films might result if the temperature drop at the surface of the substrate were sufficient to produce measurable differences in the properties of thin films deposited in that region. To reduce the amount of heat conducted away from the deposition substrate, the walls of the lightguide are preferably made as thin as possible so that the lightguide has as low of a thermal conductivity as possible, while still maintaining sufficient mechanical strength to survive vacuum pumping cycles within the deposition environment. To further reduce the amount of heat flow away from the surface of the deposition substrate, it is desirable to form the lightguide from a low thermal conductivity material. From this point of view, a ceramic tube is more desirable than an aluminum tube. However, because thermal conductance is a function of the cross sectional area of the lightguide and because an aluminum tube can have substantially thinner walls than a ceramic tube, an aluminum tube can be made to have a thermal conductance approaching that of a ceramic tube.

The lightguide is preferably physically isolated from the susceptor along almost all of its length to reduce the background radiation from the walls of the tube. Under some circumstances, however, the lightguide itself may be a part of the susceptor **12**. For example, the susceptor **12** may be formed from aluminum, the optical emissivity of the alumi-

[0120] For a wafer having a temperature above about 300° C., these technical problems include the unknown emissivity of semiconductor wafer **160**, and measurement errors caused by reflected background radiation. The unknown wafer emissivity causes large errors in temperature measurement because typical semiconductor wafer emissivities range from about 0.1 for metal films like copper to about 0.9 for oxides of certain thickness. Semiconductor wafer emissivity is a strong function of film type and thickness for both single- and multi-layer films deposited on both the front and backside of the semiconductor wafer **160**. Emissivity is also a function of the measurement wavelength and radiation collection angles employed by radiometric system **10**.

[0121] A preferred wafer temperature measurement method of this invention addresses sources of measurement error caused by unknown emissivity and reflected background radiation in processing applications that include a heated susceptor. Many semiconductor processing tools include one or more heated susceptors, which are commonly referred to as chucks, wafer holders, workpiece supports, or hot plates. Susceptors such as heated susceptor **162** are often manufactured from graphite that is typically coated with either silicon carbide or boron nitride. Susceptors may also be manufactured from aluminum, aluminum nitride, and silicon. The manufacture of susceptors, such as hot susceptor **162** is tightly controlled because its parameters directly impact the processing of semiconductor wafer **160**. For example, hot susceptor **162** has a tightly controlled surface texture, finish, and coating(s) to control among other things, contamination, heat transfer, and gas flow.

[0122] The temperature of hot susceptor **162** is also tightly controlled during processing of semiconductor wafer **160**, typically by employing closed loop feedback from sensors, such as a thermocouple **172** or a second radiometric system **174**, either of which is coupled to a CPU **176**. Other suitable temperature measuring devices include resistance temperature devices, platinum resistance thermometers, thermisters, and optical thermometers.

[0123] The semiconductor wafer temperature measurement method of this invention takes advantage of the tight control of the surface conditions and temperature of hot susceptor **162**, which tight control provides known and reproducible radiation emissions from hot susceptor **162**. The known amount of radiation emitted by hot susceptor **162** is employed as a stable radiation source for making precise reflectance measurements of semiconductor wafer **160**.

[0124] Collection optics **12** of radiometric system **10** is positioned in and sensing radiation through an opening **164** in hot susceptor **162**. Hot susceptor **162** emits emitted radiation **166**, which reflects off semiconductor wafer **160** as reflected radiation **168** that enters collection optics **12**, and is sensed by radiometric system **10**. When semiconductor wafer **160** is initially loaded in a processing chamber, it is relatively cold and, therefore, emits very little radiation. At this time, while semiconductor wafer **160** is separated from hot susceptor **162** by a gap **170**, most of the radiation sensed by radiometric system **10** is reflected radiation **168** originating from hot susceptor **162**. Semiconductor wafer **160** is then moved toward hot susceptor **162**, while radiometric system **10** makes multiple real-time measurements of reflected radiation **168**. Because the amount of reflected radiation **168** varies as gap **170** diminishes toward zero, radiometric system **10** senses information indicative of the reflectance and roughness of semiconductor wafer **160**. Semiconductor wafer **160** typically comes to rest on hot susceptor **162** as shown in dashed lines.

[0125] A process tool, typically a robot, has a fixed geometry and moves semiconductor wafer **160** toward hot susceptor **162** in a very reproducible manner. This makes it practical to calculate the amount of emitted radiation **166** by using the Planck Blackbody equation, then based on this result, to calculate the reflectivity of semiconductor wafer **160**. The emissivity of semiconductor wafer **160** can then be calculated using Kirchhoff's 1860 radiation law, which is expressed as:

$$1-R=\epsilon \tag{1}$$

[0126] where R is the reflectivity, and ϵ is the emissivity.

[0127] Using Kirchhoff's law provides nearly 100 percent accurate and valid results because hot susceptor **162** is a very uniform and diffuse emitter, thereby illuminating semiconductor wafer **160** in a nearly hemispherical (all angles) manner, which is required for proper application of the law. Skilled workers understand that actual semiconductor wafers require only about a 50° total cone angle for reliable emissivity calculations when employing Kirchhoff's law.

EXAMPLE

[0128] FIG. 18 shows a semiconductor wafer processing apparatus **180** suitable for carrying out the temperature measurement method of this invention. A horizontal transporter **182** moves semiconductor wafer **160** by its peripheral margins into position above and spaced apart from hot susceptor **162** by the distance of gap **170**, which typically ranges from about 2.54 cm (1.0 inch) to about 0.0254 mm (0.001 inch). Note that horizontal transporter **182** does not substantially block the surface of wafer **160** from hot susceptor **162** or radiometric system **10**. As wafer **160** is moved horizontally into position, cool semiconductor wafer **160** emits some emitted radiation **184**, which is sensed by radiometric system **10**. Emitted radiation **184** is initially small and increases when semiconductor wafer **160** is heated during subsequent lowering toward hot susceptor **162**. Before lowering semiconductor wafer **160**, emitted radiation **166** from hot susceptor **162** that is reflected by semiconductor wafer **160** as reflected radiation **168** provides a baseline radiation measurement for comparing with measurements taken during the subsequent downward motion of semiconductor wafer **160**. Hot susceptor **162** typically has a predetermined temperature in a range from 70° C. or less to about 1,300° C.

[0129] A vertical transporter **186** lifts semiconductor wafer **160** off horizontal transporter **182**, which moves out from under semiconductor wafer **160**. Vertical transporter **186** then commences moving semiconductor wafer **160** toward hot susceptor **162**, which movement time ranges from a fraction of a second to a few second. As semiconductor wafer **160** moves downward, its reflected emission **168** is measured by radiometric system **10** in real time as a function of diminishing gap **170**. This relationship is employed to calculate the effective reflectivity of semiconductor wafer **160**. This calculation employs the well-known relationship shown below in Eq. 2, which relates the effective or apparent emission to substrate emission when a

6,167,834 issued Jan. 2, 2001; U.S. Pat. No.

5,824,197, issued Oct. 20,
1998; and U.S. Pat. No.
6,254,328, issued Jul. 3, 2001, all of which are
incorporated herein by reference in their entireties.

5,583,737
6,167,834
5,824,197
6,254,328

US005806980A

United States Patent [19]

Berrian

[11] Patent Number: 5,806,980

[45] Date of Patent: Sep. 15, 1998

[54] METHODS AND APPARATUS FOR MEASURING TEMPERATURES AT HIGH POTENTIAL

[75] Inventor: **Donald W. Berrian**, Topsfield, Mass.

[73] Assignee: **Novellus Systems, Inc.**, San Jose, Calif.

[21] Appl. No.: **712,310**

[22] Filed: **Sep. 11, 1996**

[51] **Int. Cl.**^{6} **G01K 7/04**; G01K 13/00; G01K 1/14

[52] **U.S. Cl.** **374/179**; 374/141; 374/152

[58] **Field of Search** 374/179, 141, 374/152

[56] **References Cited**

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Primary Examiner—Diego F. F. Gutierrez

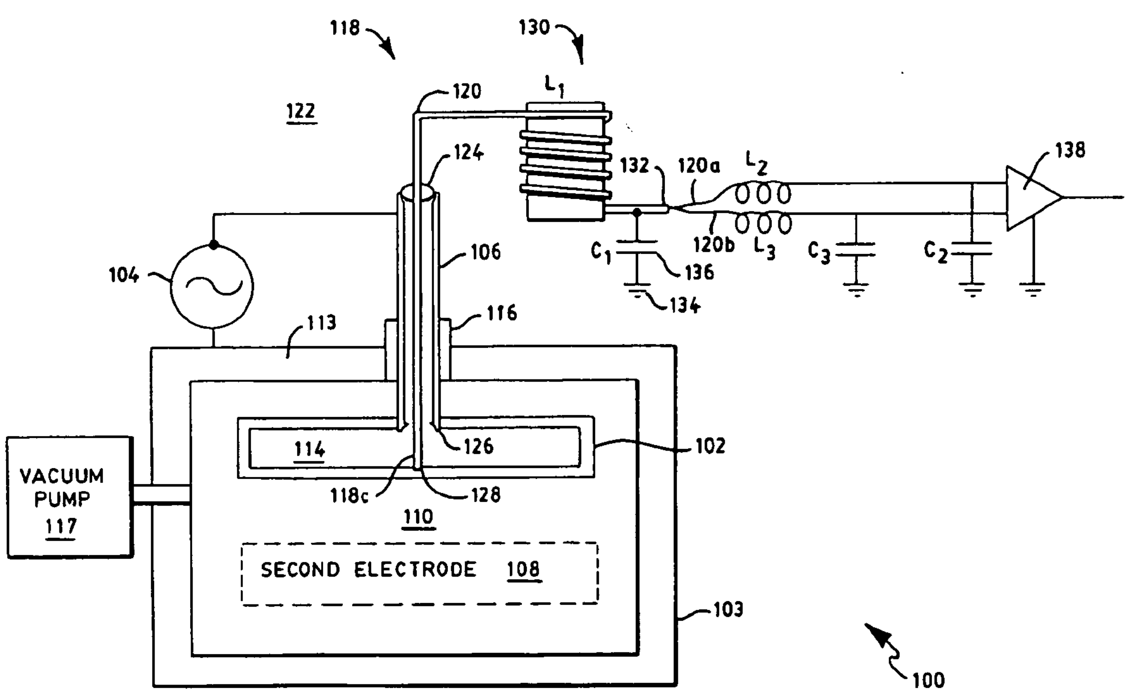
Attorney, Agent, or Firm—Curtis A. Vock

[57] **ABSTRACT**

B discloses

A thermocouple is provided which measures the temperatures of structures at high RF potential, such as an RF electrode within a plasma CVD or plasma etch reactor. The thermocouple includes an outer conductive sheath that connects to the RF electrode at a first location, and a wire pair, connected to a second location of the RF electrode, that is used to sense the RF electrode temperature. The sheath—or a conductive member connected in circuit with the sheath—is wound into a coil to form an inductor with an impedance much greater than the impedance of the RF electrode. A large capacitor grounds the coil so that the thermocouple wires, extending through the sheath, and through and out of the coil, are available for diagnostic purposes. While RF current flows through the sheath, the wires experience the same magnetic field generated by the inductive coil, substantially grounding the thermocouple. Preferably, signal conditioning electronics remove any remaining DC bias voltages. In the case of a reactor for plasma CVD or etch, the thermocouple can be enclosed within a vacuum-sealed RF feedthrough that conducts the RF energy to the electrode.

29 Claims, 6 Drawing Sheets



US 20030029835A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0029835 A1**

Yauw et al. (43) **Pub. Date: Feb. 13, 2003**

(54) **METHOD OF ETCHING ORGANIC ANTIREFLECTION COATING (ARC) LAYERS**

(76) Inventors: **Oranna Yauw**, Sunnyvale, CA (US); **Meihua Shen**, Fremont, CA (US); **Nicolas Gani**, Milpitas, CA (US); **Jeffrey D. Chinn**, Foster City, CA (US)

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(21) Appl. No.: **09/813,392**

(22) Filed: **Mar. 20, 2001**

Publication Classification

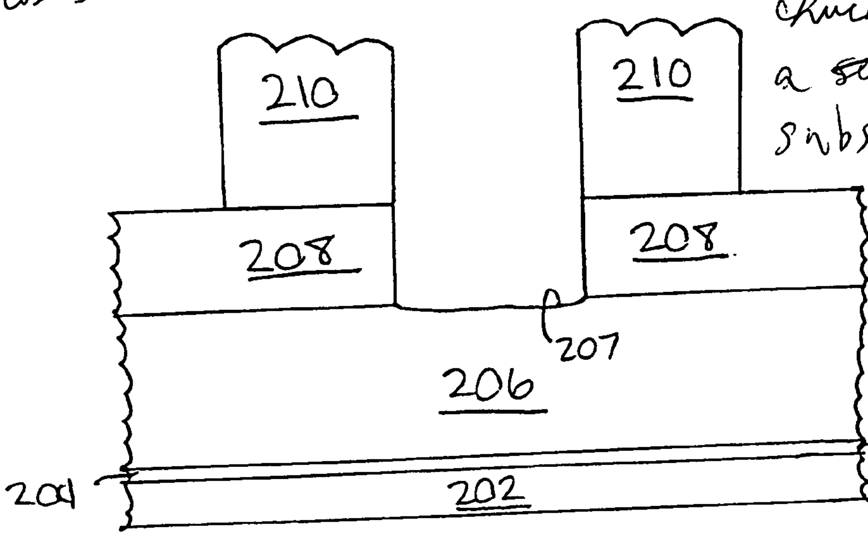
(51) **Int. Cl.**[7] **C23F 1/00**; B44C 1/22; C03C 15/00; C03C 25/68

(52) **U.S. Cl.** **216/67**

(57) **ABSTRACT**

A two-step method of etching an organic coating layer, in particular, an organic antireflection coating (ARC) layer, is disclosed. During the main etch step, the organic coating layer is etched using a plasma generated from a first source gas which includes a fluorocarbon and a non-carbon-containing, halogen-comprising gas. Etching is performed using a first substrate bias power. During the overetch step, residual organic coating material remaining after the main etch step is removed by exposing the substrate to a plasma generated from a second source gas which includes a chlorine-containing gas and an oxygen-containing gas, and which does not include a polymer-forming gas. The overetch step is performed using a second substrate bias power which is less than the first substrate bias power. The first source gas and first substrate bias power provide a higher etch rate in dense feature areas than in isolated feature areas during the main etch step, whereas the second source gas and second substrate bias power provide a higher etch rate in isolated feature areas than in dense feature areas during the overetch step, resulting in an overall balancing effect.

"Y" is cited for disclosure of plasma etching 200 devices includes source gases, and use of an electrostatic chuck for holding a ~~semiconductor wafer~~ substrate and includes a chuck pedestal temperature probe 812. The substrate may be silicon or glass, for example [0063].



US 20040208228A1

C1+8

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2004/0208228 A1**

Hashikura et al.

(43) **Pub. Date: Oct. 21, 2004**

(54) **TEMPERATURE GAUGE AND CERAMIC SUSCEPTOR IN WHICH IT IS UTILIZED**

(75) Inventors: **Manabu Hashikura**, Itami-shi (JP); **Hirohiko Nakata**, Itami-shi (JP); **Masuhiro Natsuhara**, Itami-shi (JP); **Akira Kuibira**, Itami-shi (JP)

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(73) Assignee: **SUMITOMO ELECTRIC INDUSTRIES, LTD.**, Osaka-shi (JP)

(21) Appl. No.: **10/605,519**

(22) Filed: **Oct. 6, 2003**

(30) **Foreign Application Priority Data**

Oct. 8, 2002 (JP) JP-2002-294399

Publication Classification

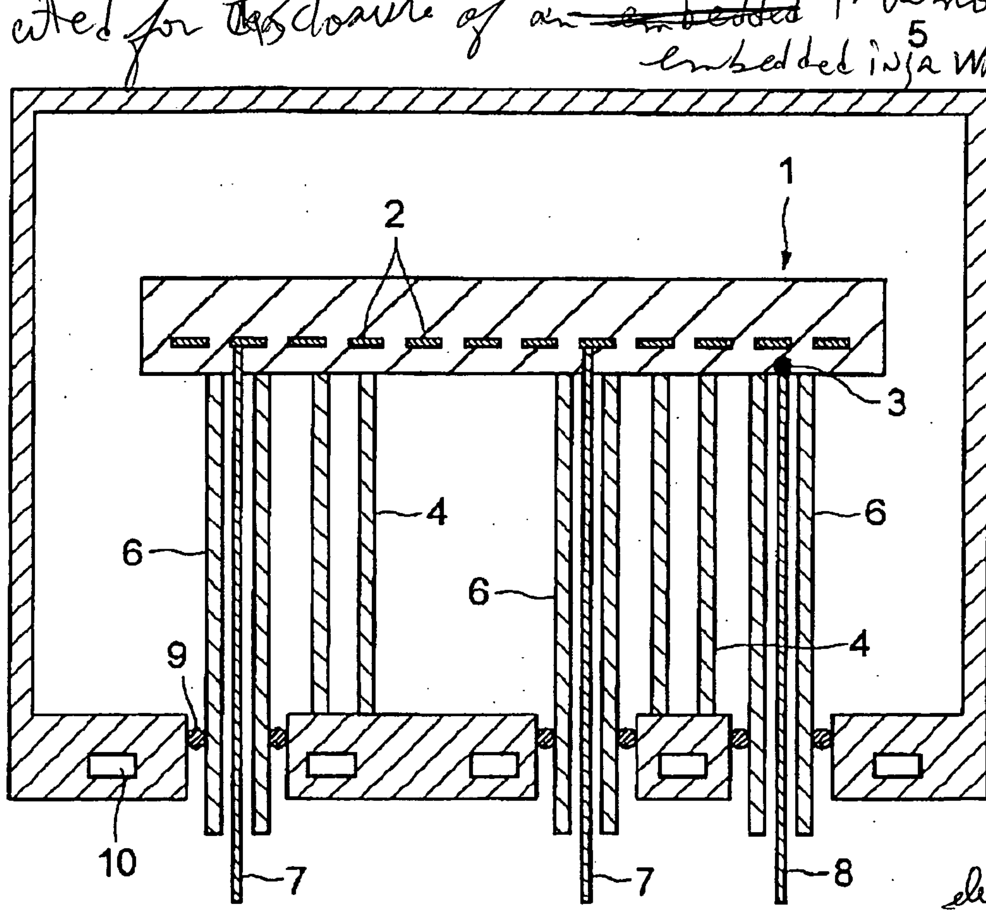
(51) **Int. Cl.**[7] **G01K 1/00**; G01K 7/00

(52) **U.S. Cl.** **374/179**; 374/208

(57) **ABSTRACT**

Temperature gauge, and ceramic susceptors and semiconductor manufacturing equipment utilizing the temperature gauge, in which the thermocouple may be easily replaced even if damaged, and in which heat from the temperature-gauging site is readily transmitted to the temperature-gauging contact, shortening time until the measurement temperature stabilizes. A temperature-gauging contact (**12**) in the tip of the thermocouple contacts, in an exposed-as-it-is state, a temperature-gauging site on a ceramic susceptor (**1**), and by means of a circular cylindrical-shaped retaining member (**11**) screwed into female threads in the ceramic susceptor (**1**) is detachably pressed upon and retained against the ceramic susceptor. Thermocouple lead lines (**13**), passing through a through-hole (**14**) in the retaining member (**11**), stretch from one end face to the other end face thereof. The retaining member may be provided with a flange having threaded holes and screwlocked into female screws in the ceramic susceptor.

"H" is cited for disclosure of a ~~embedded~~ thermocouple embedded in a WAFER-holding susceptor in a plasma processing system.



H does not disclose or fairly suggest the combination of embedded T/C and an electro-magnetic type T° measurement device, as claimed by Appl.

US 20040261721A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2004/0261721 A1**

Steger (43) **Pub. Date: Dec. 30, 2004**

(54) **SUBSTRATE SUPPORT HAVING DYNAMIC TEMPERATURE CONTROL**

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(21) Appl. No.: **10/608,091**

(22) Filed: **Jun. 30, 2003**

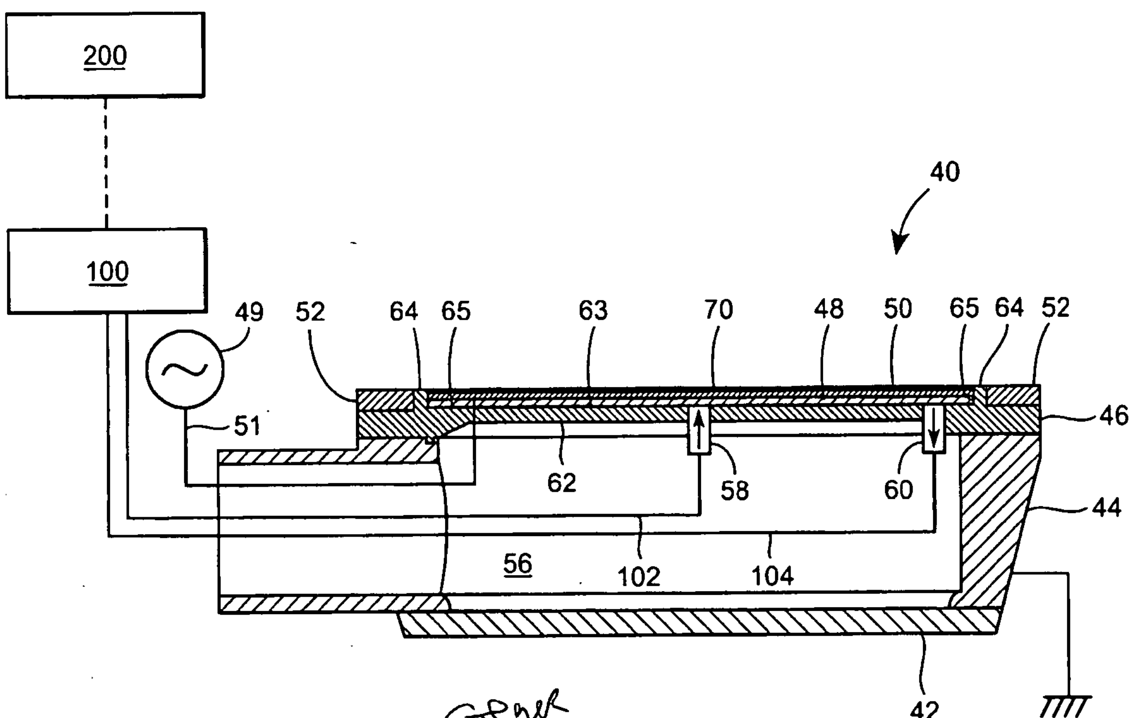
Publication Classification

(51) **Int. Cl.**[7] **C23C 16/00**

(52) **U.S. Cl.** **118/728**; 427/569; 427/248.1

(57) **ABSTRACT**

A substrate support useful for a plasma processing apparatus includes a metallic heat transfer member and an overlying electrostatic chuck having a substrate support surface. The heat transfer member includes one or more passage through which a liquid is circulated to heat and/or cool the heat transfer member. The heat transfer member has a low thermal mass and can be rapidly heated and/or cooled to a desired temperature by the liquid, so as to rapidly change the substrate temperature during plasma processing.



Steger discloses

Real-Time TC sensors

embedded in the

chuck 40

and teaches use of heat transfer gas. [91 00K7]

made of the same material as the ceramic member **146** (e.g., alumina). The heat transfer member **48** is laterally separated from the inner ring **80** by a space **82**. The electrostatic chuck **50** contacts the inner ring **80**.

[0041] The electrostatic chuck **50** is preferably bonded to the heat transfer member **48** with a suitable adhesive material, such as an elastomeric material. The adhesive preferably includes a material, such as a metallic filler, to enhance its thermal conductivity to provide sufficient heat transfer between the electrostatic chuck **50** and the underlying heat transfer member **48**. For example, the adhesive can include particles of at least one metal or metal alloy to enhance its conductivity.

[0042] As explained above, a large metallic cold plate (typically made of aluminum) can have a thickness of 1¼ inch or more and a corresponding large thermal mass. In contrast, the heat transfer member **48** preferably has a volume equal to about 5-10% of the volume of such large cold plate. Due to the significantly reduced volume of the heat transfer member **48**, the amount of heat that needs to be removed from, or added to, the heat transfer member **48** to change its temperature by a given amount, is significantly reduced as compared to such a large cold plate. The heat transfer member **48** preferably can be heated and/or cooled at a rate of from about 0.25° C./sec to about 2° C./sec. In comparison, a large cold plate, which has a large thermal mass, provides a temperature change rate that may only be as high as about 1° C./min or less. The heat transfer member **48** preferably can be controlled to a temperature ranging from about -20° C. to about 80° C. during plasma processing.

[0043] Furthermore, due to the low thermal mass of the heat transfer member **48**, the volumetric flow rate of liquid that needs to be supplied to the heat transfer member **48** to heat and/or cool the heat transfer member **48** to a desired temperature is significantly reduced as compared to the liquid flow rate needed to heat and/or cool a large cold plate having a large thermal mass.

[0044] A preferred embodiment of the substrate support **40** includes a liquid source **100**, a heat transfer gas source **150** (**FIG. 6**), and a controller **200**. As described above, the liquid source **100** (**FIG. 2**) supplies liquid to the flow passages in the heat transfer member **48**. The liquid source **100** can comprise a thermoelectric chiller (e.g., a Peltier cooler), heat exchanger, or the like, to supply liquid at a selected temperature and/or flow rate to the flow passages. The liquid source **100** can comprise a suitable pump arrangement. The chiller or the like is preferably located close to the heat transfer member **48** to reduce the distance that the liquid flows from the liquid source **100**, thereby reducing the liquid volume in the liquid path that needs to be heated or cooled, as well as reducing the response time of the liquid source.

[0045] The heat transfer gas source supplies heat transfer gas to the heat transfer gas passages. Heat transfer gas is flowed through the heat transfer gas passages, to the exposed surface of the electrostatic chuck **50**, where the heat transfer gas is distributed via openings and/or channels (not shown) formed in the exposed surface to the interface **85** between the exposed surface and the backside of the substrate **70** (**FIG. 6**). A suitable heat transfer gas supply system that provides zone cooling of the exposed surface of a substrate support is disclosed in commonly-assigned U.S. Pat. No. 5,609,720, which is incorporated herein by reference in its entirety. The heat transfer gas can be any gas having heat transfer capabilities to sufficiently transfer heat away from the substrate during plasma processing. For example, the heat transfer gas can be helium, or the like.

[0046] The controller **200** can preferably control operation of the liquid source to selectively vary parameters of the liquid supplied to the flow passages, and also control operation of the heat transfer gas source **150** to selectively vary parameters of the heat transfer gas supplied to the heat transfer gas passages. The controller **200** preferably can control operation of the liquid source **100** to control the temperature and/or flow rate of liquid supplied to the flow passages by the liquid source, and control operation of the heat transfer gas source **150** to control the flow rate and/or pressure of heat transfer gas supplied to the interface portion, to achieve a desired temperature at the exposed surface.

[0047] The controller **200** preferably receives input signals from one or more temperature sensors (not shown) positioned in the substrate support **40** to measure temperature at one or more selected locations of the substrate support **40** and/or on the substrate (e.g., at the backside). For example, temperature sensors can be disposed to measure temperature at locations proximate the exposed surface of the electrostatic chuck **50**. The temperature sensors preferably provide real time temperature measurements to enable feedback control of the operation of the liquid source **100**, as well as control of the operation of the heat transfer gas source **150**. The controller **200** can be manually operable or programmed to automatically control operation of the liquid source **100** and the heat transfer gas sources **150**.

[0048] The substrate support **40** can be used in a plasma processing apparatus in which various plasma processing operations including plasma etching, physical vapor deposition, chemical vapor deposition (CVD), ion implantation, and/or resist removal are performed. The plasma processing operations can be performed for various substrate materials including semiconducting, dielectric and metallic materials.

[0049] The substrate support **40** can provide dynamic, close temperature control, which is useful for various vacuum semiconductor processes. For example, these characteristics are useful for accurate, step-changeable temperature control in gate and shallow trench isolation ("STI") etching processes. The substrate support **40** temperature can alternatively be ramped (e.g., linearly) to form tapering sidewalls in substrates during etching, for example. The capability to rapidly change the substrate temperature is useful in various processes, such as dielectric material etch processes, in which the high power densities that are utilized can cause rapid wafer over-temperature conditions to occur unless heat is rapidly removed from the substrate.

[0050] While the invention has been described in detail with reference to specific embodiments thereof, it will be apparent to those skilled in the art that various changes and modifications can be made, and equivalents employed, without departing from the scope of the appended claims.

What is claimed is:

1. A substrate support useful in a reaction chamber of a plasma processing apparatus, the substrate support comprising:

US006575622B2

K

(12) United States Patent
Norrbakhsh et al.

(10) Patent No.: **US 6,575,622 B2**
(45) Date of Patent: **Jun. 10, 2003**

A

(54) **CORRECTION OF WAFER TEMPERATURE DRIFT IN A PLASMA REACTOR BASED UPON CONTINUOUS WAFER TEMPERATURE MEASUREMENTS USING AN IN-SITU WAFER TEMPERATURE OPTICAL PROBE**

(75) Inventors: **Hamid Norrbakhsh**, Fremont; **Mike Welch**, Livermore; **Paul Luscher**; **Siamak Salimian**, both of Sunnyvale; **Brad Mays**, San Jose, all of CA (US)

(73) Assignee: **Applied Materials Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/013,183**

(22) Filed: **Dec. 7, 2001**

(65) **Prior Publication Data**

US 2002/0048311 A1 Apr. 25, 2002

Related U.S. Application Data

(62) Division of application No. 09/547,359, filed on Apr. 11, 2000, now Pat. No. 6,353,210.

(51) **Int. Cl.**[7] **G01K 1/14**; H05B 1/00; G01J 5/08

(52) **U.S. Cl.** **374/141**; 374/131; 374/66; 219/497

(58) **Field of Search** 374/131, 141, 374/161, 132, 12, 130, 133, 124, 126, 128; 219/497, 390, 444.1, 121.43; 392/416

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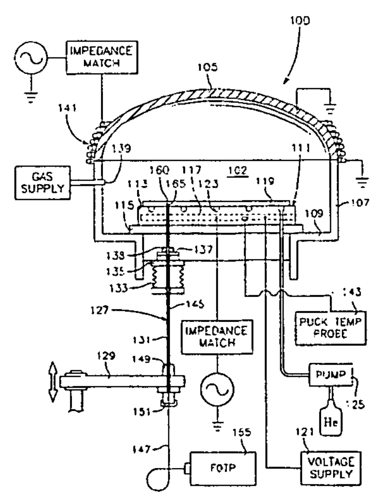
Primary Examiner—Diego Gutierrez
Assistant Examiner—Gail Verbitsky
(74) *Attorney, Agent, or Firm*—Robert M. Wallace; Joseph Bach

(57) **ABSTRACT**

The invention solves the problem of continuously monitoring wafer temperature during processing using an optical or fluoro-optical temperature sensor including an optical fiber having an end next to and facing the backside of the wafer. This optical fiber is accommodated without disturbing plasma processing by providing in one of the wafer lift pins an axial void through which the optical fiber passes. The end of the fiber facing the wafer backside is coincident with the end of the hollow lift pin. The other end is coupled via an "external" optical fiber to temperature probe electronics external of the reactor chamber. The invention uses direct wafer temperature measurements with a test wafer to establish a data base of wafer temperature behavior as a function of coolant pressure and a data base of wafer temperature behavior as a function of wafer support or "puck" temperature. These data bases are then employed during processing of a production wafer to control coolant pressure in such a manner as to minimize wafer temperature deviation from the desired temperature.

4 Claims, 5 Drawing Sheets



use of Helium pressure to control WAFER T°

US006703592B2

(12) **United States Patent**
Van Bilsen

(10) **Patent No.:** **US 6,703,592 B2**
(45) **Date of Patent:** **Mar. 9, 2004**

Cite

(54) **SYSTEM OF CONTROLLING THE TEMPERATURE OF A PROCESSING CHAMBER**

(75) Inventor: **Frank B. M. Van Bilsen**, Phoenix, AZ (US)

(73) Assignee: **ASM America, Inc.**, Phoenix, AZ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/309,383**

(22) Filed: **Dec. 2, 2002**

(65) **Prior Publication Data**

US 2003/0080112 A1 May 1, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/739,863, filed on Dec. 18, 2000, now Pat. No. 6,507,007, which is a continuation of application No. 09/495,765, filed on Feb. 1, 2000, now Pat. No. 6,191,399.

(51) **Int. Cl.**[7] **H05B 1/02**

(52) **U.S. Cl.** **219/497**; 219/497; 219/501; 219/505; 219/494; 219/486; 392/416; 392/418; 374/1; 374/102; 374/103; 118/724; 118/725

(58) **Field of Search** 219/497, 501, 219/505, 494, 486; 392/416, 418; 374/1, 102, 103; 118/724, 725

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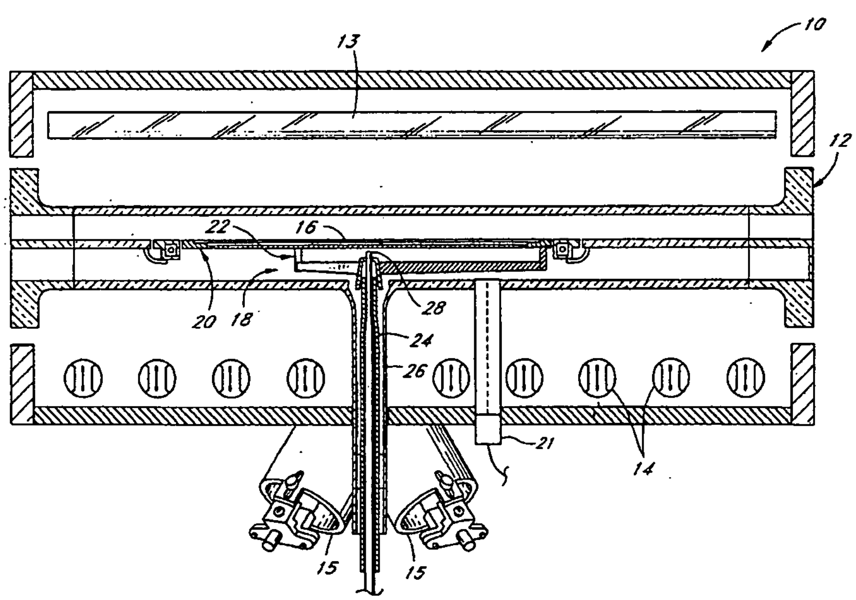
Primary Examiner—Mark Paschall
(74) *Attorney, Agent, or Firm*—Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

A CVD processing reactor employs a pyrometer to control temperature ramping. The pyrometer is calibrated between wafer processing by using a thermocouple that senses temperature during a steady state portion of a processing operation.

31 Claims, 5 Drawing Sheets



US006106148A

United States Patent [19]

Moslehi et al.

[11] **Patent Number: 6,106,148**

[45] **Date of Patent: Aug. 22, 2000**

[54] **APPARATUS INCLUDING INTEGRAL ACTUATOR WITH CONTROL FOR AUTOMATED CALIBRATION OF TEMPERATURE SENSORS IN RAPID THERMAL PROCESSING EQUIPMENT**

[75] Inventors: **Mehrdad M. Moslehi**, Los Altos; **Yong Jin Lee**, San Jose, both of Calif.

[73] Assignee: **CVC, Inc.**

[21] Appl. No.: **09/344,419**

[22] Filed: **Jun. 25, 1999**

Related U.S. Application Data

[62] Division of application No. 08/680,244, Jul. 10, 1996, Pat. No. 6,004,029.

[60] Provisional application No. 60/000,989, Jul. 10, 1995.

[51] **Int. Cl.**[7] **G01K 15/00**; H01L 21/02; F27D 11/00

[52] **U.S. Cl.** **374/1**; 374/141; 392/416; 219/390; 427/521; 427/557; 438/796

[58] **Field of Search** 374/1, 141; 392/416; 219/390; 427/521, 557; 438/796

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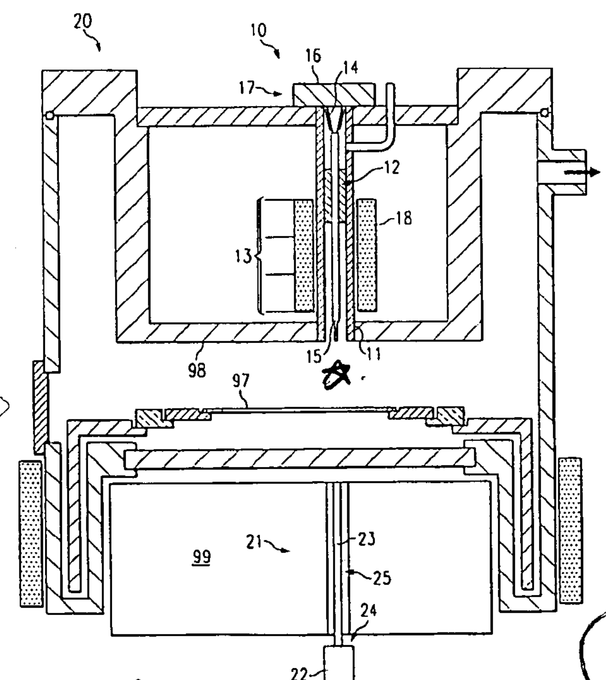
Primary Examiner—Diego Gutierrez
Assistant Examiner—Stanley J. Pruchnic, Jr.
Attorney, Agent, or Firm—Gray Cary Ware & Freidenrich LLP

[57] **ABSTRACT**

This invention presents an automatic calibration system and method for calibration of a substrate temperature sensor in a thermal processing equipment, such as a rapid thermal processing system. The calibration system includes a temperature-sensitive probe associated with the substrate temperature sensor to calibrate the substrate temperature sensor and an actuator to position the temperature-sensitive probe relative to the substrate during a calibration cycle. The actuator and temperature-sensitive probe of the automatic calibration system can be incorporated into the thermal processing equipment in order to maintain the thermal processing equipment cleanliness and integrity during a calibration cycle, and to allow rapid automated calibration. In the preferred embodiment of this invention, the temperature-sensitive probe and its actuator are implemented in the gas showerhead assembly of a rapid thermal processing system.

50 Claims, 5 Drawing Sheets



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3, 4

1
2
13
14
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Substrate

glass panel!
7:35-38

NOT ISOTHERMAL STAGE

NOT physical map of chuck

T/C measures wafer

US005848842A

United States Patent [19]

[11] **Patent Number: 5,848,842**

Peuse et al.

[45] **Date of Patent: Dec. 15, 1998**

[54] **METHOD OF CALIBRATING A TEMPERATURE MEASUREMENT SYSTEM**

[75] Inventors: **Bruce W. Peuse**, San Carlos; **Gary E. Miner**, Newark; **Mark Yam**, San Jose, all of Calif.

[73] Assignee: **Applied Materials, Inc.**, Santa Clara, Calif.

[21] Appl. No.: **650,744**

[22] Filed: **May 20, 1996**

Related U.S. Application Data

[62] Division of Ser. No. 359,302, Dec. 19, 1994, Pat. No. 5,660,472.

[51] **Int. Cl.**[6] **G01K 51/00**

[52] **U.S. Cl.** **374/1**; 374/2

[58] **Field of Search** 374/1, 2, 126, 374/128

[56] **References Cited**

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4,956,538	9/1990	Moslehi .	
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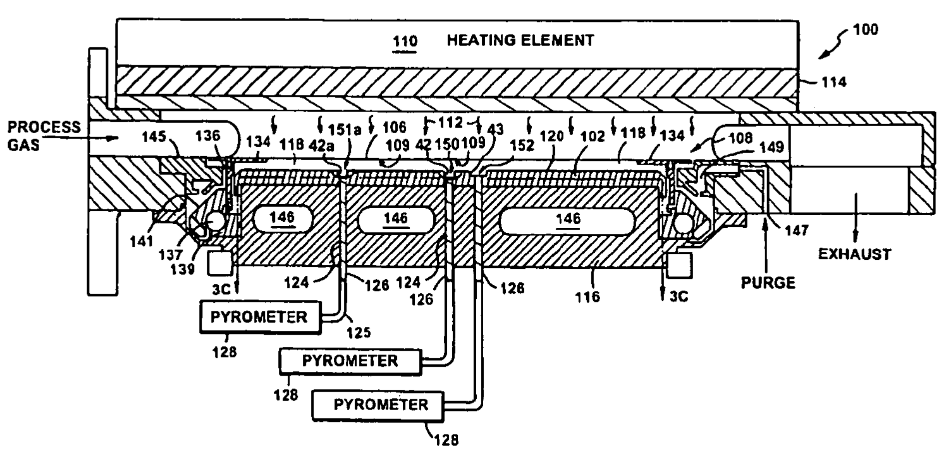
Primary Examiner—William A. Cuchlinski, Jr.
Assistant Examiner—Andrew Hirshfeld
Attorney, Agent, or Firm—Fish & Richardson P.C.

[57] **ABSTRACT**

A method of calibrating a temperature measurement system including the steps of heating a first substrate having a high emissivity value to a first process temperature; while the first substrate is at the first process temperature, calibrating a first probe and a second probe to produce temperature indications from the first substrate that are substantially the same, the first probe having associated therewith a first effective reflectivity and the second probe having associated therewith a second effective reflectivity, the first and second effective reflectivities being different; heating a second substrate having a low emissivity value to a second process temperature, the low emissivity value being lower than the high emissivity value; with the second substrate at the second process temperature, using both the first probe and the second probe to measure the temperature of the second substrate, the first probe producing a first temperature indication and the second probe producing a second temperature indication different from the first temperature indication; measuring a sensitivity of the temperature indication produced by the first probe to changes in substrate emissivity; and by using the measured sensitivity and the first and second temperature indications, computing a correction factor for the first probe, the correction factor to be applied to subsequent temperature readings of the first probe to produce corrected temperature readings.

12 Claims, 12 Drawing Sheets



US006798036B2

(12) **United States Patent**
Yun

(10) **Patent No.: US 6,798,036 B2**
(45) **Date of Patent: Sep. 28, 2004**

(54) **TEMPERATURE MEASURING METHOD AND APPARATUS IN SEMICONDUCTOR PROCESSING APPARATUS, AND SEMICONDUCTOR PROCESSING METHOD AND APPARATUS**

(75) Inventor: **Mo Yun**, Yamanashi (JP)

(73) Assignee: **Tokyo Electron Limited**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/431,528**

(22) Filed: **May 8, 2003**

(65) **Prior Publication Data**

US 2003/0206574 A1 Nov. 6, 2003

Related U.S. Application Data

(62) Division of application No. 09/995,769, filed on Nov. 29, 2001, now Pat. No. 6,579,731.

(30) **Foreign Application Priority Data**

Dec. 1, 2000 (JP) 2000-367071

(51) **Int. Cl.**[7] **H01L 31/058**; H01L 21/66; H01L 21/00; G01K 15/00; G01K 17/00

(52) **U.S. Cl.** **257/467**; 438/14; 438/54; 374/2; 374/29; 374/120

(58) **Field of Search** 438/10; 374/2, 374/29, 120, 43

(56) **References Cited**

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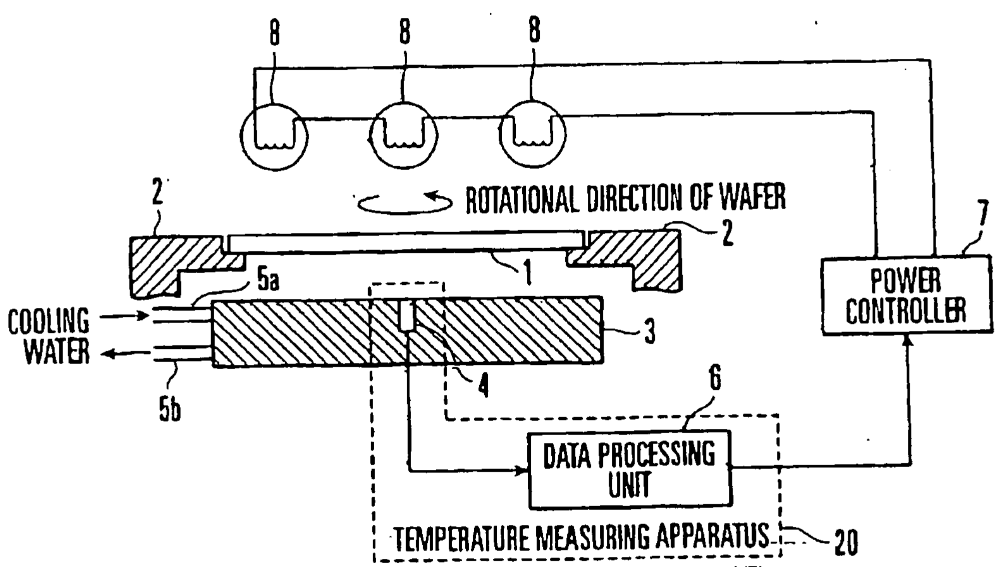
Primary Examiner—Jack Chen
Assistant Examiner—David L. Hogans
(74) *Attorney, Agent, or Firm*—Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.

(57) **ABSTRACT**

A temperature measuring method for a target substrate to be thermally processed in a semiconductor processing apparatus under a predetermined process condition is provided. This method includes the steps of detecting a heat flux supplied from at least part of the target substrate and detecting a temperature of a sensor by using the sensor facing the target substrate, and calculating a temperature of the target substrate from a parameter, including a thermal resistance between the sensor and the target substrate under the predetermined process condition, the detected heat flux, and the temperature of the sensor. The sensor is arranged opposite to heating means, through the target substrate, which heats the target substrate. The parameter may be obtained in advance by calibration.

4 Claims, 3 Drawing Sheets



US 20030033110A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0033110 A1
Schietinger et al. (43) Pub. Date: Feb. 13, 2003

(54) WAFER TEMPERATURE MEASUREMENT METHOD FOR PLASMA ENVIRONMENTS

(76) Inventors: **Charles W. Schietinger**, Milwaukie, OR (US); **Ronald A. Palfenier**, Oregon City, OR (US)

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PORTLAND, OR 97204 (US)

(21) Appl. No.: **10/197,230**

(22) Filed: **Jul. 16, 2002**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/872,750, filed on May 31, 2001.

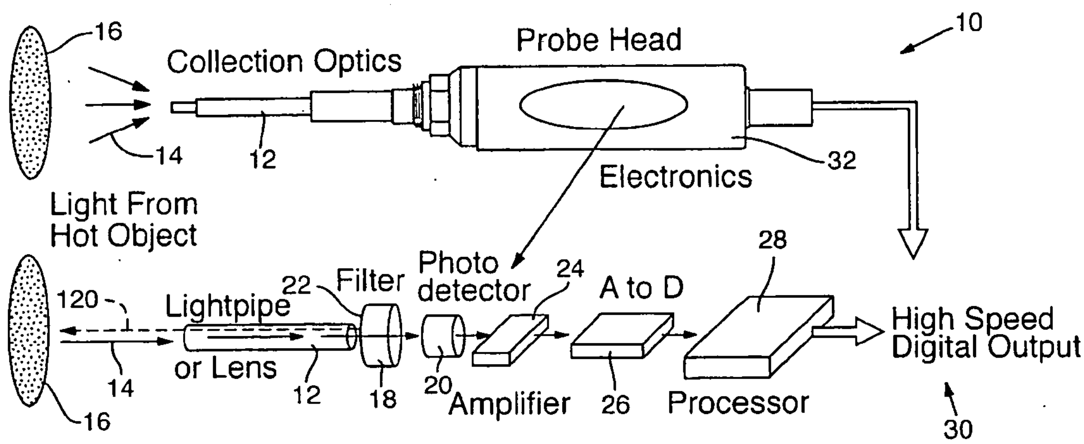
(60) Provisional application No. 60/209,168, filed on Jun. 2, 2000. Provisional application No. 60/209,074, filed on Jun. 2, 2000. Provisional application No. 60/209, 076, filed on Jun. 2, 2000. Provisional application No. 60/217,012, filed on Jul. 10, 2000.

Publication Classification

(51) **Int. Cl.**[7] **G01K 11/30**
(52) **U.S. Cl.** **702/134**

(57) **ABSTRACT**

The temperature of a semiconductor wafer (**160**) is measured while undergoing processing in a plasma (**168**) environment. At least two pyrometers (**162, 164**) receive radiation from, respectively, the semiconductor wafer and the plasma in a plasma process chamber. The first pyrometer receives radiation from either the front or rear surface of the wafer, and the second pyrometer receives radiation from the plasma. Both pyrometers may be sensitive to the same radiation wavelength. A controller (**170**) receives signals from the first and second pyrometers and calculates a corrected wafer emission, which is employed in the Planck Equation to calculate the wafer temperature. Alternatively, both pyrometers are positioned beneath the wafer with the first pyrometer sensitive to a first wavelength where the wafer is substantially opaque to plasma radiation, and the second pyrometer is sensitive to a wavelength where the wafer is substantially transparent to plasma radiation.



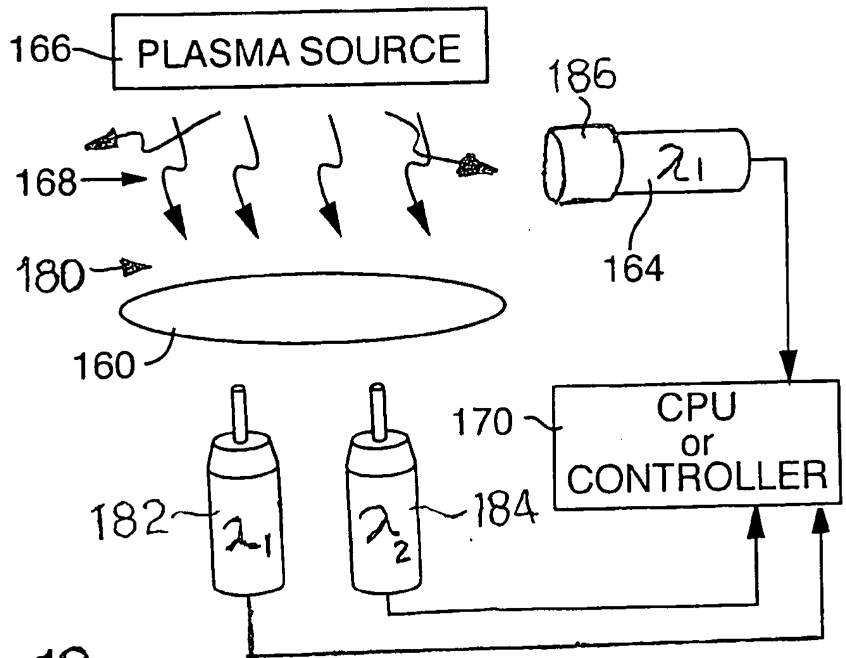

166
PLASMA SOURCE
186
168
λ1
164
180
160
170
CPU
or
CONTROLLER
182
λ1
λ2
184

FIG. 18

US006406924B1

(12) **United States Patent**
Grimbergen et al.

(10) **Patent No.:** **US 6,406,924 B1**
(45) **Date of Patent:** **Jun. 18, 2002**

(54) **ENDPOINT DETECTION IN THE FABRICATION OF ELECTRONIC DEVICES**

(75) Inventors: **Michael N. Grimbergen**, Redwood City; **Thorsten B. Lill**, Sunnyvale, both of CA (US)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/286,493**

(22) Filed: **Apr. 5, 1999**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/062,520, filed on Apr. 17, 1998.

(51) **Int. Cl.**[7] **H01L 21/00**

(52) **U.S. Cl.** **438/9**; 156/345; 216/60; 356/357; 438/723; 438/743

(58) **Field of Search** .... 438/9, 14, 16, 438/723, 743; 216/56, 60; 156/345 MT; 356/357

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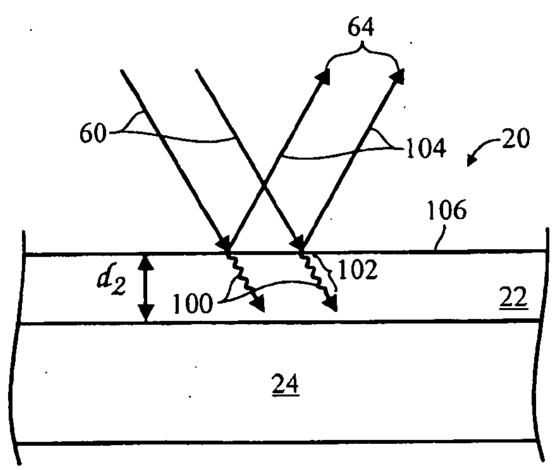
Primary Examiner—William A. Powell
(74) *Attorney, Agent, or Firm*—Janah & Associates

(57) **ABSTRACT**

A chamber **28** comprises a radiation source **58** capable of emitting radiation having a wavelength that is substantially absorbed in a predetermined pathlength in a thickness of a layer **22** on a substrate, and a radiation detector **62** adapted to detect the radiation. The radiation is substantially absorbed in a first thickness of the layer **22**, and after at least partial processing of the layer **22**, is at least partially transmitted through a second thickness of the layer **22** and reflected by one or more underlayers **24** of the substrate **20**.

96 Claims, 11 Drawing Sheets



US006299346B1

(12) **United States Patent**
Ish-Shalom et al.

(10) **Patent No.: US 6,299,346 B1**
(45) **Date of Patent: Oct. 9, 2001**

(54) **ACTIVE PYROMETRY WITH EMISSIVITY EXTRAPOLATION AND COMPENSATION**

(75) Inventors: **Yaron Ish-Shalom**, Kiryat Tivon (IL); **Yael Baharav**, Palo Alto, CA (US)

(73) Assignee: **C. I. Systems LTD**, Migdal Haemek (IL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/521,113**

(22) Filed: **Mar. 7, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/123,371, filed on Mar. 8, 1999.

(51) **Int. Cl.**[7] **G01K 5/06**

(52) **U.S. Cl.** **374/126**; 374/127; 374/128; 374/130; 374/134; 374/131

(58) **Field of Search** 374/134, 126, 374/128, 130, 132, 131, 127, 121

(56) **References Cited**

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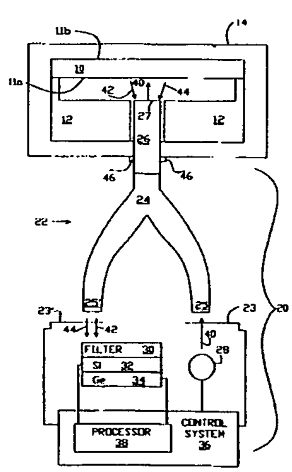
Primary Examiner—Diego Gutierrez
Assistant Examiner—Gail Verbitsky
(74) *Attorney, Agent, or Firm*—Mark M. Friedman

(57) **ABSTRACT**

A method and apparatus for active pyrometric measurement of the temperature of a body whose emissivity varies with wavelength. The emissivity is inferred from reflectivity measured at two wavelengths in an irradiation wavelength band and extrapolated to a wavelength in an emission wavelength band. The extrapolated emissivity is used to correct a blackbody estimate of the temperature of the body in the emission wavelength band. The extrapolation, being temperature-dependent, is done iteratively. Both reflectivity and emission measurements are performed via a common optical head that is shaped, and is positioned relative to the body, so that the optical head has a sufficiently large solid angle of acceptance that the measured temperature is independent of superficial roughness of the body.

35 Claims, 6 Drawing Sheets



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US-PAT-NO: 5823681

DOCUMENT-IDENTIFIER: US 5

TITLE: Multipoint temp semiconductor wafe

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Current US Class - CLAS (3):
392

Current US Cross Reference Cla (2):
374/1

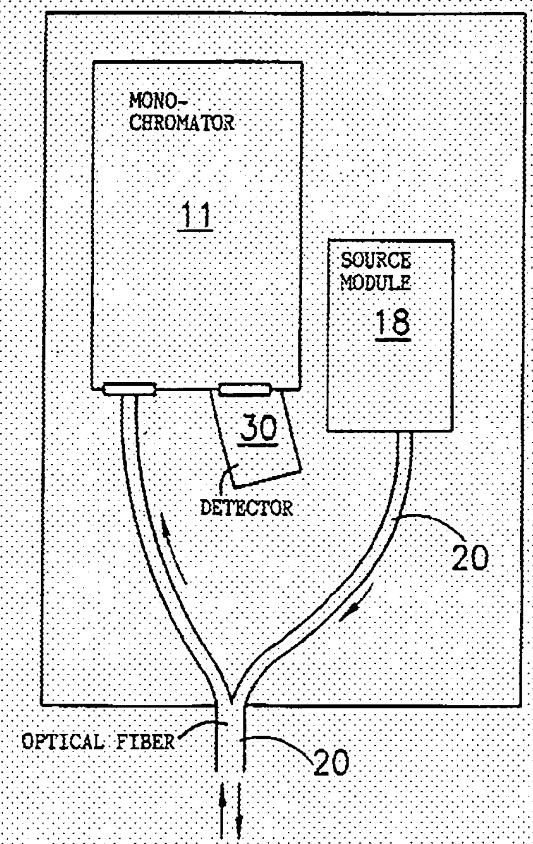

FIG.2

Details Text Image HTML Details Text Image HTML Full

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7		US 6164816 A
8	☑	US 6086245 A
9 ☑		US 6056433 A
10 ☑		US 6004030 A
11 ☑		US 5820261 A
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13 ☑		US 4134299 A
14 ☑		US 3902368 A
15 ☑		US 3776039 A
16		US 3757207 A

Details | Text | Image | HTML

APPARATUS FOR INFRARED PYROMETER CALIBRATION IN A THERMAL PROCESSING SYSTEM

This is a continuation of U.S. application Ser. No. 08/506,902, filed Jul. 26, 1995, now U.S. Pat. No. 5,820,261.

BACKGROUND OF THE INVENTION

The present invention relates to calibrating pyrometers that are used in thermal processing systems.

In rapid thermal processing (RTP), a substrate is heated quickly to a high temperature, such as 1200° C., to perform a fabrication step such as annealing, cleaning, chemical vapor deposition, oxidation, or nitridation. Particularly given the submicron dimensions of current devices, to obtain high yields and process reliability, the temperature of the substrate must be precisely controlled during these thermal processing steps. For example, to fabricate a dielectric layer 60–80 Å thick with a uniformity of ±2 Å, which is typical of requirements in current device structures, the temperature in successive processing runs cannot vary by more than a few ° C. from the target temperature. To achieve this level of temperature control, the temperature of the substrate is measured in real time and in situ.

Optical pyrometry is a technology that is used to measure substrate temperatures in RTP systems. An optical pyrometer using an optical probe samples the emitted radiation intensity from the substrate, and computes the temperature of the substrate based on the spectral emissivity of the substrate and the ideal blackbody radiation-temperature relationship.

When the system is first set up, the optical probe must calibrated so that it produces a correct temperature reading when exposed to the radiation coming from the heated substrate. In addition, during repeated use, the temperature sensed by the probe might change over time and thus it will be necessary to recalibrate the probe or at least detect the change that has occurred so that corrective action can be taken. For example, the light pipe which is used to sample the radiation being emitted from the substrate as it is being heated, may become dirty or chipped, connections along the optical column transferring the sampled light to the pyrometer may loosen, or the electronic components in the pyrometer may "drift".

A commonly used method of calibrating the pyrometer is to use a special substrate or wafer in the chamber. The special substrate, which can be purchased from commercial sources, has a previously measured, known emissivity and it has an "embedded" thermocouple which is attached to the substrate with a ceramic material. When the substrate is heated, its actual temperature is indicated by the thermocouple. Since the substrate's emissivity is known, the radiation that is actually emitted by the substrate can be easily calculated by multiplying the intensity of radiation that would be expected from by an ideal black body that is at the predetermined temperature times the emissivity of the substrate. This is the radiation level that will be sampled by the optical probe of the pyrometer. The pyrometer is adjusted so that it produces a temperature reading that corresponds to the actual temperature.

Unfortunately, this method has drawbacks. The actual temperature of the substrate may in fact be different than the temperature measured by the thermocouple. First, the presence of the embedded thermocouple and the ceramic material causes the area with the thermocouple to have a different

temperature than other parts of the wafer, i.e., it disturbs the temperature profile on the substrate. Second, at high temperatures (e.g., 1000° C. as is commonly found in RTP processes) the joint between the wafer and thermocouple tends to degrade, so that after four or five uses the thermocouple readings become unreliable. Because of these shortcomings, this calibration technique cannot really guarantee pyrometer accuracy that is better than ten to fifteen ° C.

In addition, there are difficulties associated with placing a thermocoupled substrate inside the chamber and making electrical connection to the thermocouple.

SUMMARY OF THE INVENTION

In general, in one aspect, the invention features an apparatus for calibrating a temperature probe (e.g., a pyrometer). In the invention, a light emitting diode is held in a cavity of a calibration instrument and positioned to emit light through an aperture into an input end of the temperature probe. The calibration instrument emits light having a predetermined intensity. There is an indicia indicating a black-body temperature from that the light from the calibration instrument simulates.

In general, in another aspect, the invention features a method for calibrating a temperature probe. In the method, stable light of a predetermined intensity shines from a calibration instrument into an input end of the temperature probe. The stable light simulates radiation from a black body at a temperature T_O. The temperature probe is used to produce a temperature reading T_1 in response to the light. The difference between T_O and T_1 is used to generate corrected measurements from the temperature probe during processing within the thermal processing system.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe inside a thermal processing chamber. In the apparatus, an alignment tool has a light source having a stable intensity. The light source is held in a cavity and positioned to emit light through an aperture during calibration. A first alignment structure of the alignment tool engages a corresponding first alignment feature of the chamber. The aperture is located in a position relative to the first alignment structure so that during calibration the aperture is aligned with an input of the temperature probe.

Implementations of the invention may include the following features. The first alignment structure may comprise a pin and the first alignment feature may comprise a pinhole in a reflector plate in the chamber and located in proximity to the input end of the probe. The first alignment structure may comprise a projection adapted to fit a lift pin hole in a reflector plate in the chamber. The cavity and aperture may be located in a body and the body may include a second alignment structure to engage a corresponding second alignment feature of the alignment tool. The body may be removable from the cavity. The body may be cylindrical, and the second alignment feature may comprise a cylindrical conduit having an annular lip. The alignment tool may be a disk and the second alignment feature may comprise a conduit through the disk.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe outside a thermal processing chamber. The apparatus features an alignment tool having a cavity and an aperture leading thereto. The alignment tool has an alignment structure to engage an input end of the probe. A light source having a stable intensity is held in the cavity and positioned to emit

Details | Text | Image | HTML | Full

Chemical vapor Deposition -- Optical Pyrometry

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3	☐	☐	US 6612737 B1
4	☐	☐	US 6508584 B2
5	☐	☐	US 6200023 B1
6	☐	☐	US 6190037 B1
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U.S. Patent Jul. 11, 2000 Sheet 2 of 9 **6,086,245**

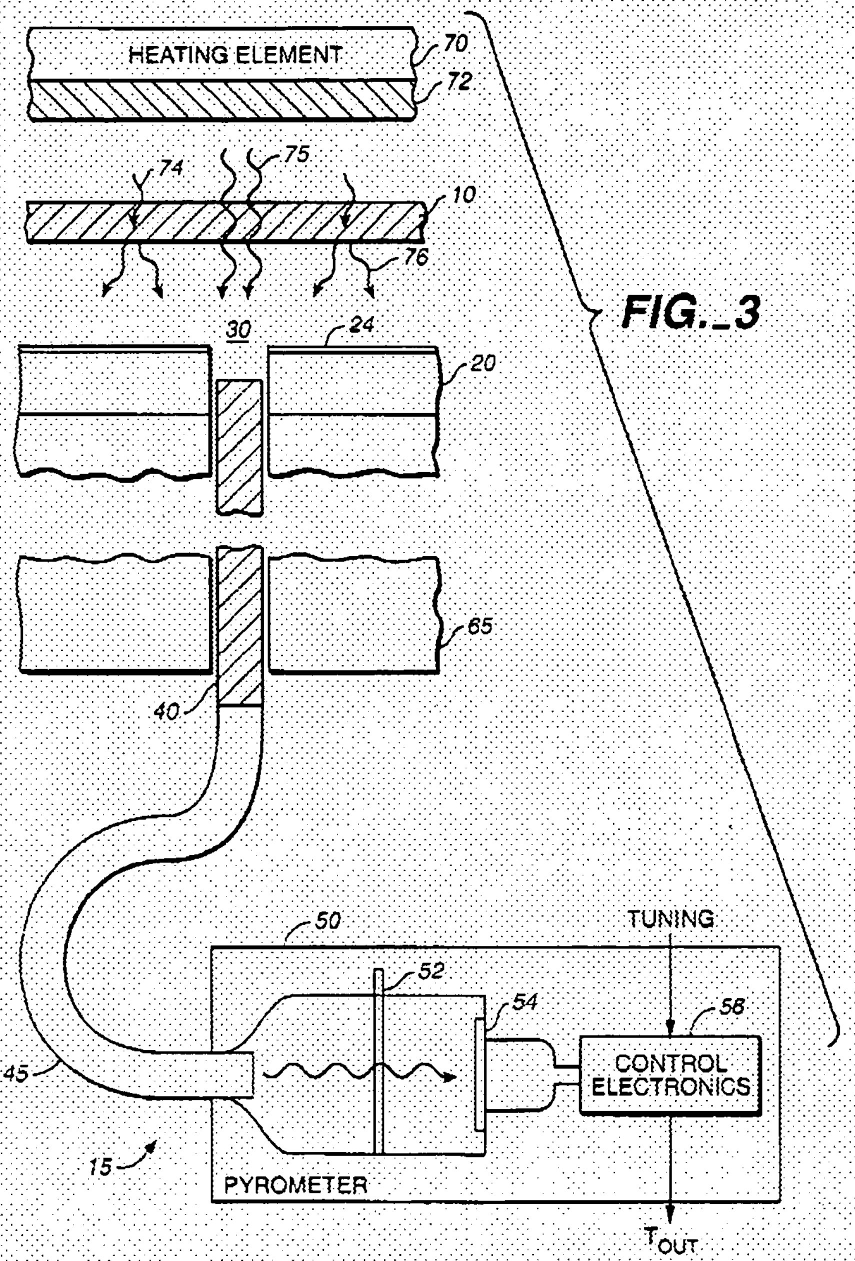

FIG._3

Details Text Image HTML Full

Bandpass optical filter 52

Start

between semiconductor device 12 and bakeplate 20 that is 1%, preferably less than 0.1% of the area of first major surface 22 underlying semiconductor device 12. According to one specific example of a protuberance distribution as shown in FIG. 1*d*, six tubular protuberances 56 having a height of 150 micrometers, an outside diameter of about 1.6 mm, and an inside diameter of about 0.8 mm are arranged in two triangular patterns positioned at two different radii 58 and 60 from the center of bakeplate 20. With this approach, the total contact area between semiconductor device 12 and bakeplate 20 is so small as to be negligible, yet semiconductor device 12 (and annular member 40 if present) is adequately supported. As another example, a large number of protuberances 56 can be formed in an array over the entire surface 22, e.g., as a triangular pattern in which adjacent protuberances 56 are about 4 mm to 6 mm apart. In such an array, individual protuberances 56 are typically 0.1 mm to 0.5 mm, preferably about 0.2 mm to 0.3 mm, in diameter.

Bakeplate 20 may optionally be provided with one or more flow channels 38 in order to provide fluid communication gap 62 between bakeplate 20 and semiconductor device 12. Gap 62 may be filled with a gas such as ordinary air or a more conductive gas if it is desired to enhance the thermal conductivity between bakeplate 20 and semiconductor device 12. For example, helium gas is approximately seven times more conductive than air. Introducing a gas into gap 62 might also help reduce the tendency of semiconductor device edge 13 to overheat relative to other portions of semiconductor device 12. Alternatively, in the presence of an appropriate seal between semiconductor device 12 and bakeplate 20, gap 62 may be used to pull a slight vacuum, e.g., a vacuum on the order of 3000 Pa to 14,000 Pa, against wafer 12 in order to help hold wafer 12 in position. For example, an annular shaped protuberance (not shown) could be provided on bakeplate 20 proximal to edge 13 to help form such a seal.

Still referring to FIGS. 1*a*, 1*b*, and 1*c*, the temperature of semiconductor device 12 is desirably monitored directly or indirectly during baking and chilling operations so that the heat output of bakeplate 20 can be controlled using a suitable feedback control methodology, such as PID control. According to the direct approach for monitoring wafer temperature, a suitable temperature sensor (not shown) can be attached directly to semiconductor device 12. However, for high volume production applications, this approach is not really practical or desirable, because the direct approach requires the additional processing steps of attaching and detaching temperature sensor(s) to a semiconductor device every time a new semiconductor device is to be inserted into apparatus 10 for processing. Additionally, wafers typically support sensitive componentry that could be adversely affected by contact with a temperature sensor.

Accordingly, it is much more desirable to monitor the temperature of semiconductor device 12 indirectly by attaching a suitable temperature sensor to annular member 40, particularly when the thermal capacity of annular member 40 is matched to that of wafer 12 as discussed above. Under such circumstances, the actual temperature of the top surface of semiconductor device 12 substantially corresponds to the temperature of the top surface of annular member 40 at substantially all times during baking and/or chilling, even during temperature ramps. Indeed, the difference in temperature between the top surface of annular member 40 and the top surface of semiconductor device 12 is substantially constant and more preferably negligible, as a practical matter. Accordingly, when indirectly monitoring the temperature of the top surface of semiconductor device 12 using a temperature sensor coupled to the top surface of annular member 40, a simple correction, if needed, can be applied to the measured temperature in order to account for the temperature difference, if any, between the top surfaces of semiconductor device 12 and annular member 40.

The temperature sensor to be used in the present invention may be any suitable temperature sensor that is capable of sensing temperature at rapid intervals with stability and consistency over long periods of time. A variety of suitable temperature sensing devices are known of which a resistive thin-film (RTD) sensor is most preferred. Several suitable types are available from a variety of commercial sources. As one example, a suitable thin-film RTD sensor is commercially available under the trade designation 517422 PDX40A from Minco Products, Inc., Minneapolis, Minn. This sensor incorporates a platinum wire having a diameter of about 50 micrometers encased in a "KAPTON" brand polyamide resin layer having a thickness of about 100 micrometers (i.e., the encased wire has an overall diameter of about 250 micrometers). The RTD sensor may be bonded into the desired position using a suitable temperature resistant adhesive such as a polyamide resin, a polyimide resin, a polyimideamide resin, a silicone resin, an epoxy resin, microtextured polytetrafluoroethylene, combinations of these, or the like.

As an alternative to buying an RTD temperature sensor, an RTD temperature sensor may be constructed in situ, or constructed in-house and then subsequently bonded into position, from an electroresistive material with RTD characteristics using any suitable formation technique known in the art such as a sputter-etching process. For example, to form an RTD sensor in situ, a layer of a suitable electroresistive metal such as platinum may be deposited at the desired position and then etched to form an RTD temperature sensor. A layer of insulation is desirably deposited between the sensor and the component to which the sensor is attached. The layer of insulation may comprise any insulating material of the type conventionally used in the microelectronics industry, including polytetrafluoroethylene, polyamide, polyimide, polyamideimide, silicon dioxide, silicon nitride, combinations of these, and the like.

In some applications, an RTD sensor used by itself may not have the requisite agility needed to provide meaningful control of wafer temperature. In those situations, a particularly preferred temperature sensor is a hybrid sensor system including a combination of a relatively slow and stable first temperature sensing device (preferably an RTD sensor) and a relatively fast and unstable second sensor device (preferably a thermocouple). The fast/unstable second sensor device is used to sense temperature of wafer 12 with greater speed, while temperature measurements sensed by the slow/stable first sensor device are used to calibrate the second sensor automatically on-line so that the second sensor measurements remain accurate and reliable over time.

The concept of using the hybrid temperature sensor is based upon the appreciation that thermocouples can sense temperature at rates as fast as 1000 to 2000 Hz, yet tend to have relatively poor temperature sensing stability over time. On the other hand, although a typical RTD temperature sensor might have a lower sensing speed, e.g., temperature sensing capabilities of only up to about 10 Hz, RTD sensors generally have excellent temperature sensing stability over long periods of time. Thus, by using the RTD sensor to calibrate the thermocouple automatically on-line, the hybrid sensor system obtains the benefits of both kinds of sensing

United States Patent [19]

Pecot et al.

[11] **Patent Number: 4,854,727**

[45] **Date of Patent: Aug. 8, 1989**

[54] **EMISSIVITY CALIBRATION APPARATUS AND METHOD**

[75] Inventors: **Michel Pecot**, Palo Alto; **Jaim Nulman**, Sunnyvale, both of Calif.

[73] Assignee: **AG Processing Technologies, Inc.**, Sunnyvale, Calif.

[21] Appl. No.: **114,542**

[22] Filed: **Oct. 26, 1987**

[51] **Int. Cl.**[4] **G01N 3/60**; G01N 17/00

[52] **U.S. Cl.** **374/57**; 374/12; 374/121

[58] **Field of Search** 374/134, 132, 130, 131, 374/12, 13, 15, 112, 115, 121, 170, 179, 204, 57, 120, 137

[56] **References Cited**

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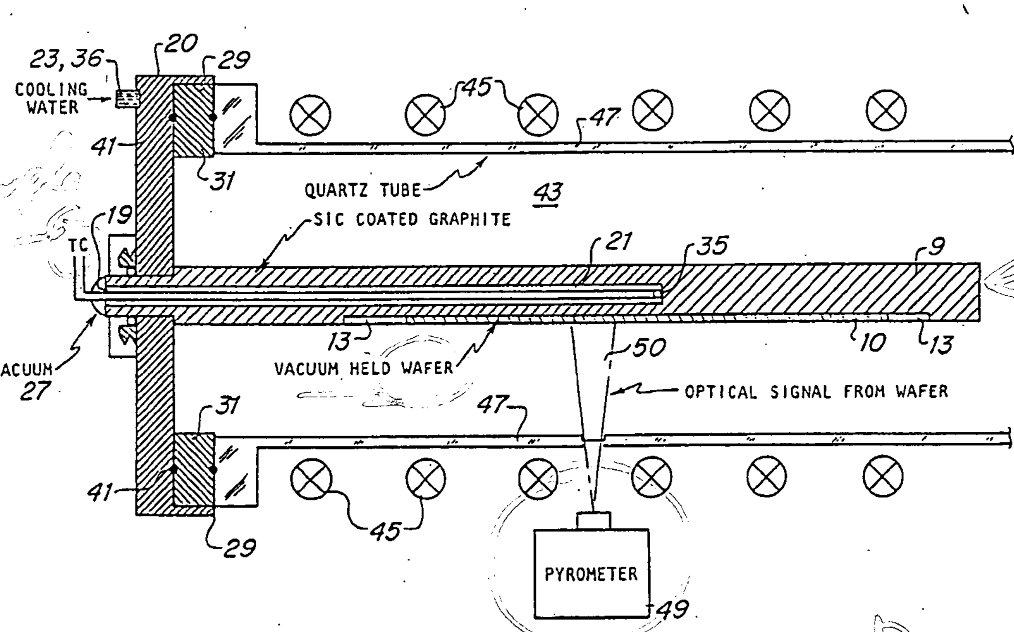
Primary Examiner—Roy N. Envall, Jr.

Attorney, Agent, or Firm—A. C. Smith

[57] **ABSTRACT**

An improved method and apparatus are disclosed for calibrating the emissivity characteristics of a semiconductor wafer within a processing chamber by supporting a sample wafer on a graphite susceptor within the chamber and by comparing the temperature measured within the susceptor in close proximity to the center of the wafer with the temperature measured by the emission of radiation from the surface of the wafer through the walls of the processing chamber. Temperature measurements subsequently made from the radiation emitted from the surface of similar wafers are corrected with reference to the measurement made of the temperature within the susceptor on the sample wafer.

7 Claims, 3 Drawing Sheets



US005823681A

United States Patent [19]

Cabib et al.

[11] **Patent Number: 5,823,681**

[45] **Date of Patent: Oct. 20, 1998**

Cite / use

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[54] **MULTIPOINT TEMPERATURE MONITORING APPARATUS FOR SEMICONDUCTOR WAFERS DURING PROCESSING**

[75] Inventors: **Dario Cabib**, Timrat; **Robert A. Buckwald**, Ramat Ishay; **Michael E. Adel**, Zichron Yakov, all of Israel

[73] Assignee: **C.I. Systems (Israel) Ltd.**, Migdal Haemek, Israel

[21] Appl. No.: **604,997**

[22] PCT Filed: **Jul. 12, 1995**

[86] PCT No.: **PCT/US95/08521**

§ 371 Date: **Feb. 29, 1996**

§ 102(e) Date: **Feb. 29, 1996**

[87] PCT Pub. No.: **WO96/04534**

PCT Pub. Date: **Feb. 15, 1996**

[30] **Foreign Application Priority Data**

Aug. 2, 1994 [IL] Israel 110549

[51] **Int. Cl.**^{6} **G01J 5/08**; G01J 5/02; G01J 5/28; G01J 5/62; G01J 5/06

[52] **U.S. Cl.** **374/126**; 374/130; 374/128; 374/133; 374/131; 374/1; 392/416; 118/724

[58] **Field of Search** 374/1, 9, 126, 374/131, 133, 128, 130; 356/44; 250/338.1; 392/416; 219/390, 405, 411; 118/50.1, 724

[56] **References Cited**

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Primary Examiner—Diego F. F. Gutierrez
Attorney, Agent, or Firm—Mark M. Friedman

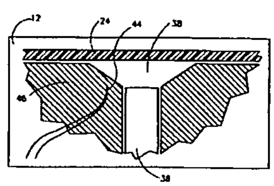
[57] **ABSTRACT**

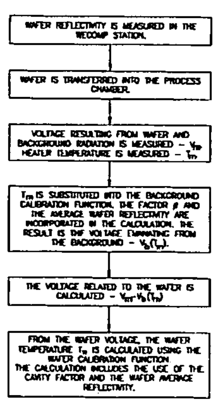
An emissivity compensating non-contact system for measuring the temperature of a semiconductor wafer. The system includes a semiconductor wafer emissivity compensation station for measuring the reflectivity of the wafer at discrete wavelengths to yield wafer emissivity in specific wavelength bands. The system further includes a measurement probe which is optically coupled to a semiconductor process chamber. The probe senses wafer self emission using one or more optical detectors and a light modulator. A background temperature determining mechanism independently senses the temperature of a source of background radiation. Finally, a mechanism calculates the temperature of the semiconductor wafer based on the reflectivity, self-emission and background temperature.

21 Claims, 7 Drawing Sheets

Confirm col 4

Known radiation (see ... 4:2) Col 5: 1-





Monochromator (11) (Fig 2) Col 4: 25-38

Wafer

Bandpass optical filter (45) Fig 5B Col 3:

Gas flow (Fig 7A) ... to equilibrium Col 6: 12-15

US006062729A

United States Patent [19]

Ni et al.

[11] **Patent Number: 6,062,729**

[45] **Date of Patent: May 16, 2000**

In A plasma processing system

[54] **RAPID IR TRANSMISSION THERMOMETRY FOR WAFER TEMPERATURE SENSING**

[75] Inventors: **Tuqiang Ni**, Fremont; **Michael Barnes**, San Francisco, both of Calif.

[73] Assignee: **Lam Research Corporation**, Fremont, Calif.

[21] Appl. No.: **09/050,897**

[22] Filed: **Mar. 31, 1998**

[51] **Int. Cl.**[7] **G01J 5/10**; G01N 25/00

[52] **U.S. Cl.** **374/161**; 374/121; 374/124; 374/126; 374/128; 374/131; 374/137

[58] **Field of Search** 374/121, 127, 374/130, 131, 161, 2, 128, 124, 126

[56] **References Cited**

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Primary Examiner—G. Bradley Bennett
Assistant Examiner—Gail Verbitsky
Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis, L.L.P.

[57] **ABSTRACT**

A method and apparatus for measuring the temperature of an object, such as a substrate, during processing. The object is illuminated by a light source. Infrared light that is transmitted through the object is then collected and transmitted to a photodiode. The amount of light transmitted through the substrate varies as a function of substrate temperature. The photodiode generates a signal in response to the light transmitted to the photodiode and an analyzing device generates a real-time temperature reading based on the signal. The photodiode may include at least one silicon photodiode or a plurality of photodiodes made from germanium or indium/gallium/arsenide.

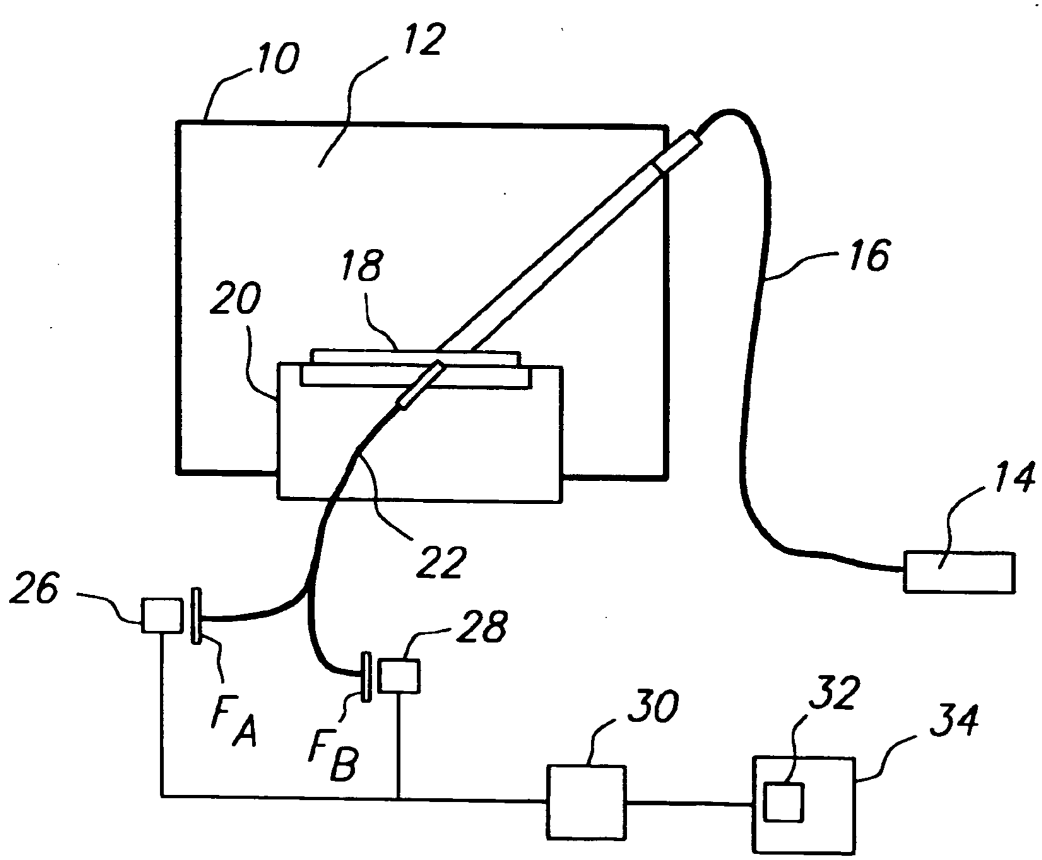
Related

T measurement Devices

Band Pass,

IR transm,

21 Claims, 3 Drawing Sheets



US005388909A

United States Patent [19]

Johnson et al.

[11] **Patent Number: 5,388,909**

[45] **Date of Patent: Feb. 14, 1995**

Cite SAME CLAIM 6

[54] **OPTICAL APPARATUS AND METHOD FOR MEASURING TEMPERATURE OF A SUBSTRATE MATERIAL WITH A TEMPERATURE DEPENDENT BAND GAP**

[76] Inventors: **Shane R. Johnson; Christian Lavoie,** both of 2626 Tennis Crescent, Vancouver, B. C., Canada, V6T 2E1; **Mark K. Nissen,** 215 - 2190 West 7th Avenue, Vancouver, B. C., Canada, V6K 4K7; **J. Thomas Tiedje,** 1752 Wesbrook Crescent, Vancouver, B. C., Canada, V6T 1W1

[21] Appl. No.: **121,521**

[22] Filed: **Sep. 16, 1993**

[51] **Int. Cl.**[6] **G01K 11/00; G01J 5/48**

[52] **U.S. Cl.** **374/161;** 374/120; 356/44

[58] **Field of Search** 374/120, 161, 131; 356/44

[56] **References Cited**

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Primary Examiner—Diego F. F. Gutierrez

Attorney, Agent, or Firm—Oyen Wiggs Green & Mutala

[57] **ABSTRACT**

An optical method and apparatus for measuring the temperature of a substrate material with a temperature dependent bandgap. The substrate is illuminated with a broad spectrum lamp and the bandgap is determined from the spectrum of the diffusely scattered light. The spectrum of the light from the lamp is sufficiently broad that it covers the spectral range above and below the bandgap of the substrate. Wavelengths corresponding to photon energies less than the bandgap of the substrate are transmitted through the substrate and are reflected from the back surface of the substrate as well as from the front surface while the wavelengths corresponding to photon energies larger than the bandgap are reflected only from the front surface. If the front surface is polished the front surface reflection will be specular while if the back surface is rough the reflection from the back surface will be non-specular. The back surface reflection is detected with a detector in a non-specular location. From the wavelength of the onset of the non-specular reflection the bandgap can be determined which gives the temperature. The temperature is determined from the knee in the diffuse reflectance spectrum near the bandgap.

17 Claims, 18 Drawing Sheets

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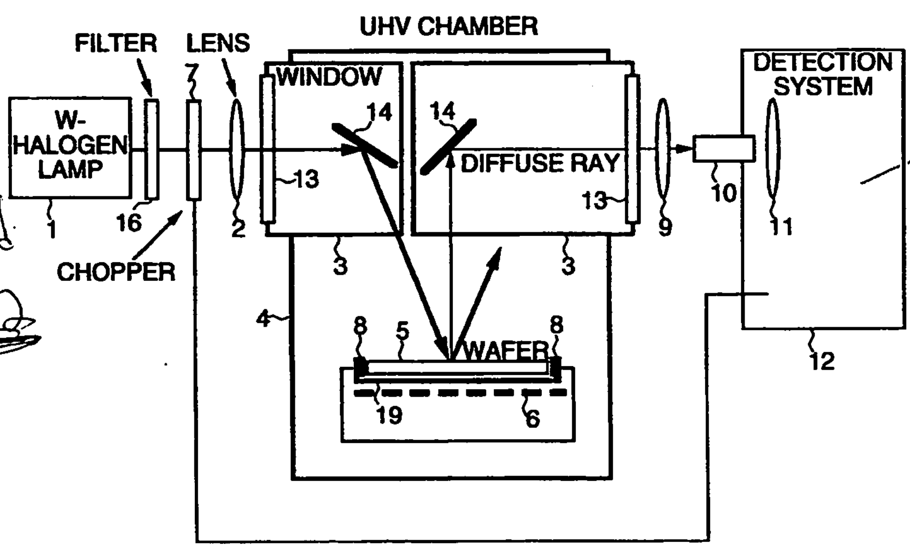

monochrom

Bandgap

Cite

claim 7

Same

United States Patent [19]

Poenisch et al.

[11] **Patent Number: 5,021,980**

[45] **Date of Patent: Jun. 4, 1991**

[54] **REMOTE MEASUREMENT OF TEMPERATURE**

[75] Inventors: **Paul Poenisch**, Santa Clara; **Keith Hansen**, San Jose, both of Calif.

[73] Assignee: **LSI Logic Corporation**, Milpitas, Calif.

[21] Appl. No.: **313,577**

[22] Filed: **Feb. 21, 1989**

[51] Int. Cl.[5] **G06F 15/42**; G06F 15/46; G06F 15/20; G01N 25/00

[52] U.S. Cl. **364/557**; 364/550; 374/9; 374/120

[58] **Field of Search** 374/9, 100, 109, 126, 374/161, 120; 356/43, 45, 51, 320; 364/525, 550, 557

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Primary Examiner—Kevin J. Teska

Attorney, Agent, or Firm—Skjerven, Morrill, MacPherson, Franklin & Friel

[57] **ABSTRACT**

A method for determination of the true temperature T and true radiative emissivity of a body at temperature T, using measurements of total energy radiated by the body in two or more adjacent wave length ranges $\lambda_1 \leqq \lambda \leqq \lambda_2$ and $\lambda_3 \leqq \lambda \leqq \lambda_4$; the wave length ranges may partially overlap or may be adjacent but non-overlapping.

6 Claims, 3 Drawing Sheets